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Tests of Concretes Containing Air-entraining Portland Cements or Air-entraining Materials Added to Batch at Mixer*

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Member American Concrete Institute

SYNOPSIS

This paper presents some of the more significant results obtained in extensive laboratory studies made in connection with the construction of 18 experimental road projects, and in several separate laboratory investigations conducted during the past six years with air-entraining portland cements, and with air-entraining materials added at the mixer. Concrete specimens from nearly every experimental road project and from all laboratory series were subjected to scaling and to freezing and thawing tests. These specimens consisted of slabs made in the field from the concrete used in the pavement, of cores drilled from the pavement, and of many prisms made in the laboratory from the cements used in the roads. The laboratory studies included also many slabs and prisms made with various cements.

Resistance to scaling, and to freezing and thawing while immersed, was markedly improved when the concrete was made with air-entraining portland cements, or with air-entraining materials added at the mixer. Increase in air content of the concrete caused reductions in flexural and compressive strength. Each percentage point increase in air content reduced the modulus of rupture 2 to 3 per cent and the compressive strength 3 to 5 per cent. Taking into account both strength and resistance to freezing and thawing, excellent performance was obtained when the total amount of entrained air in the fresh concrete was about 3 per cent, or about 2 percentage points higher than that of concrete without air-entraining additions. With this percentage of air, the loss in strength was generally not more than 6 per cent in flexure and 10 per cent in compression. Higher air contents than 3 per cent caused greater reductions in strength without any compensating increase in resistance to scaling and to freezing and thawing. The performance under service conditions of experimental paving projects constructed since 1938 with air-entraining portland cements parallels the results of the laboratory studies.

*Presented by the author March 1, 1944, at the Institute's 40th Annual Convention, Chicago.
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1—INTRODUCTION

During the past few years the Portland Cement Association has, in cooperation with other interested agencies conducted numerous laboratory and field studies of concrete with a view to increasing its resistance to the type of disintegration that occurs when relatively new concrete pavements are subjected to heavy and frequent applications of raw flake calcium or granular sodium chloride, or to repeated applications of granular materials mixed with these salts. Some idea of the large amount of work that has been done on this problem and on the allied problem of increasing the durability of concrete exposed to severe climatic conditions may be obtained from a review of the numerous reports relating to these subjects that have been issued in recent years.‡

The studies have consistently shown that the resistance of concrete to disintegration by frost action and by the direct application of salts for ice and snow removal may be vastly increased by grinding with the cement, or adding to the batch, minute quantities of materials which will increase the amount of air or other gas entrapped in the concrete while it is plastic.

Besides increasing the resistance to salt and frost action, the addition of minute amounts of these air-entraining agents produces other effects in the concrete, among which are a decrease in unit weight and a reduction in strength about in direct proportion to the increase in air content. In addition to the greatly increased resistance to scaling and to freezing and thawing, there are other beneficial effects produced by the air-entraining materials which offset any strength reduction that may occur, such as increased workability and cohesiveness of the concrete, and reduction in bleeding tendency.

This paper describes some of the more significant results of the tests of the concrete specimens made in connection with the studies of air-entraining portland cements and air-entraining materials added to the batch during mixing of the concrete.

Air-entraining materials

Materials which have been used in laboratory or in field tests for the purpose of entraining air into mortars and concretes include:

1) Natural wood resins such as rosin and Vinsol resin,

2) Animal or vegetable fats and oils such as tallow and olive oil and their fatty acids such as stearic and oleic acids,

3) A commercial product known as Liqro which consists largely of oleic and resin acids,

‡See list of references to the literature appended to this report.

4) Various wetting agents such as the alkali salts of sulfated and sulfonated organic compounds,

5) Water soluble soaps* of resin acids and animal and vegetable fatty acids,

6) Miscellaneous materials such as the sodium salts of petroleum sulfonic acids, etc.

In addition to the foregoing materials, hydrogen peroxide and aluminum powder have been used to entrain gas (oxygen or hydrogen) in concrete in some supplementary tests carried out in the laboratory. In this paper the presence of these gases is treated the same as air and will be referred to as such.

Method of introducing air-entraining materials into concrete

Introduction of the air-entraining materials into the concrete was accomplished in two ways, by grinding with the cement clinker, or by adding directly to the batch of concrete materials, either in powdered or paste form, or in a solution in water or other liquids.

For most of the experimental field projects thus far constructed, the air-entraining materials have been ground with the cement, consequently field experience with adding the materials directly to the batch has been rather limited and practically all of the work done thus far on this method has been carried out in the laboratory.

It has been found that Vinsol resin is not very effective in entraining air when added to the batch in powdered form. Therefore it generally was added in a *NaOH*-water solution. Soluble soaps of organic fatty acids and inorganic bases were added directly to the batch with satisfactory results.

Scope of Studies

Experimental road projects of considerable size have been built in cooperation with the highway departments of 10 different states in most of which severe climatic conditions exist. Smaller experimental projects have been built along street railway tracks in two northern cities where salt applications are frequent and heavy during the winter season. To supplement the field studies many series of tests have been carried out in the laboratory with a wide variety of air-entraining cements and with different kinds and amounts of air-entraining materials.

Methods of test for surface scaling and resistance to freezing and thawing

Since the primary purpose of these field and laboratory investigations was to develop methods of increasing the resistance of concrete to surface

*A. H. White and J. H. Bateman in a paper entitled "Soaps as Integral Waterproofings for Concrete" which appeared in the Proceedings of the American Concrete Institute, v. 22, p. 535, 1926, described the effects of soluble and insoluble soaps, when used integrally in small amounts for waterproofing concrete. One of the effects noted was that the use of soluble soaps which cause foaming and the entrainment of air will cause a reduction in strength.

scaling and disintegration caused by the application of salts to remove ice, most attention was given to determining the effect on the concrete of repeated applications of salts to remove ice frozen on the surface of slab specimens. These slab specimens were generally 3 by 6 by 15-in. They were subjected to a method of test designated as the "surface scaling test." This involved freezing about a-¼in. layer of water on the top surface and then thawing the ice thus formed by the direct application of raw flake calcium chloride in an amount equivalent to about 2.4 lb. per sq. yd. of surface. This cycle was repeated once each day until the surface of the specimen was badly scaled, or until it had been given 100 to 300 or more cycles without developing serious scaling.

Slab specimens for surface scaling tests were made on several of the field projects and in practically all of the laboratory series of tests. On a few of the early experimental road projects, concrete slabs also were made for freezing and thawing tests while immersed in water or in a 10 per cent calcium chloride solution. For those field projects where slab specimens were not made, concrete cores were drilled from the pavement and subjected to freezing and thawing while immersed in a 10 per cent calcium chloride solution.

In addition to the slabs for the surface scaling test, concrete prisms (generally 3x3x11¼-in.) were made in the laboratory and tested for resistance to repeated freezing and thawing while immersed in a 10 per cent calcium chloride solution or in tap water. The following criteria were used to evaluate the resistance of these prism specimens to the freezing and thawing treatment.

1) Linear expansion,
2) Change in modulus of elasticity (sonic method),
3) Loss in weight,
4) Loss in strength after given number of cycles,
5) In one series of tests the permeability of concrete specimens was determined after various cycles of freezing and thawing.

Shrinkage during storage in air, expansion during storage in water and change in modulus of elasticity and strength during these storages were also determined for many of the test prisms. Detailed information was obtained on the composition of the fresh concrete, including water, cement and aggregate contents, total air voids, and weight per cu. ft. Generally the air content of the concrete was obtained from yield tests on the freshly-mixed batch,* but in the case of gas-producing additions,

*The air content was calculated by subtracting from the calibrated volume of a 4 by 8 by 12-in. truncated cone measure, the sum of the absolute volumes of all solids and liquids required to fill the measure as determined from the weight of the fresh concrete. In the case of hydrogen peroxide and aluminum powder, most of the gas was generated after the concrete was placed in the molds, making it necessary to use density measurements on the hardened concrete.

such as hydrogen peroxide and aluminum powder, it was obtained from density measurements on the hardened concrete specimens. In all of the laboratory tests reported in this paper the concrete was mixed in an open tub type mixer for 2 minutes after adding the mixing water.

2—TESTS OF CONCRETE CONTAINING AIR-ENTRAINING PORTLAND CEMENTS

Early tests with wetting agents

In 1935 and 1936 some exploratory tests were made to determine the effect of a number of wetting agents on the water requirements, plasticity and strength of portland cement mortars. In a mix of fixed proportions all of the materials tried increased the air content of the mortar, but reduced the water content, the cement content, the unit weight and the compressive strength. The increase in air content, which apparently resulted from the promotion of foaming, was found to have a decided effect on the smoothness, and ease of manipulation of the mortars. Those materials which produced the greatest increase in air content produced the greatest improvement in workability. The reduction in compressive strength with increase in air content was obtained with all of the wetting agents used even though some of the materials permitted a substantial reduction in water content. In these exploratory studies durability tests were not made and it was not until more extensive studies were undertaken subsequently that the beneficial effect of entrained air on resistance to scaling and to freezing and thawing of concrete was definitely established.

Effect of increased air content, as produced by different methods, on resistance of concrete to freezing and thawing

In Table 1(a) and (b) are results of freezing and thawing tests of concrete the air voids of which were increased, over those normally present, by the following four different methods:

1) Adding hydrogen peroxide to a batch of normal portland cement concrete,
2) Adding a commercial wetting agent to a batch of normal portland cement concrete,
3) Using an air-entraining portland cement ground with Vinsol resin,*
4) Using a portland cement ground with powdered aluminum.

The hydrogen peroxide was the commercial product. It was added in the form of a 10 per cent solution near the end of the mixing period. Hydrogen peroxide decomposes completely in the presence of any finely divided metallic oxide to H_2O and oxygen. In these tests the oxygen liberated produced voids in the concrete after the concrete was placed

*Vinsol resin, a commercial product manufactured by the Hercules Powder Co., consists substantially of the petroleum-hydrocarbon insoluble fraction of a coal-tar hydrocarbon extract of pine wood.

TABLE 1—RESULTS OF FREEZING AND THAWING TESTS OF CONCRETES FOR DIFFERENT AIR-ENTRAINING MATERIALS

(a) *Tests of 2 by 2 by 9½-in. Concrete Prisms—Series J-336*

Cement: Commercial normal and air-entraining portland cements (both of Type 1) from the same plant.
Aggregate: Cow Bay sand and gravel graded from 0 to ¾-in.
Concrete: Cement content 6.0 sk. per cu. yd.; slump 3 to 5 in.
Prisms cured 1 day in molds in moist room, 6 days in water, then 4 months in air of laboratory. Prisms immersed in water for 7 hr. before freezing and thawing. Prisms frozen and thawed in tap water one cycle per day.
Values of air content are for the hardened concrete.

Addition		Air Content, %	Cycles of Freezing and Thawing in Tap Water							
Kind	% by Wt. of Cmnt.		0	10	20	30	60	90	120	200
LINEAR EXPANSION DURING FREEZING AND THAWING—%										
None	0.0	1.2	0	.071	.219	.316	Disc. at 30 cycles			
H_2O_2 added at mixer	0.5	3.9	0	.005	.016	.014	.033	.043	.055	.117
Commercial wetting agent "A" added at mixer	0.01	4.1	0	.016	.012	.014	.018	.030	.042	.064
Vinsol resin ground with cement	0.05	3.4	0	.006	.015	.013	.021	.031	.040	.053
YOUNG'S MODULUS (SONIC), lb. per sq. in. x 10-⁶										
None	0.0	1.2	4.1	3.4	2.9	1.5	Disc. at 30 cycles			
H_2O_2 added at mixer	0.5	3.9	4.0	4.3	4.4	4.6	4.6	4.0	3.8	2.9
Commercial wetting agent "A" added at mixer	0.01	4.1	3.9	4.1	4.3	4.4	4.6	4.3	4.2	4.1
Vinsol resin ground with cement	0.05	3.4	4.0	4.4	4.5	4.6	4.6	4.5	4.2	4.2
LOSS IN WEIGHT OF PRISMS DURING FREEZING AND THAWING—%										
None	0.0	1.2	0	0	0	0	Disc. at 30 cycles			
H_2O_2 added at mixer	0.5	3.9	0	0	0	0	2	4	5	10
Commercial wetting agent "A" added at mixer	0.01	4.1	0	0	0	0	2	3	4	7
Vinsol resin ground with cement	0.05	3.4	0	0	0	0	3	4	5	8

(b) *Tests of 3 by 3 by 11¼-in. Concrete Prisms—Series J-345*

Cement: A mixture of portland cement (Type 1) clinkers from 4 plants, ground in a small laboratory mill with temperature maintained between 210 and 220°F.
Aggregate: Cow Bay sand and gravel graded from 0 to ¾-in.
Concrete: Cement content 6.0 sk. per cu. yd.; slump approximately 4 in.
Prisms cured 14 days in moist room, about 17 days in air of laboratory, then immersed in water for 4 days before freezing and thawing.
Prisms frozen and thawed in tap water, 2 cycles per day.

Addition Ground with Cement, % by Weight	Air Content, % *	Cycles of Freezing and Thawing in Tap Water							
		0	25	50	75	100	150	200	300
LINEAR EXPANSION DURING FREEZING AND THAWING—%									
None	1.3	0	.02	.08	.12	Disc. at 75 cycles			
.0066% Aluminum Powder	2.5	0	.01	.03	.04	.04	.06	.07	.10
YOUNG'S MODULUS (SONIC), lb. per sq. in. x 10-⁶									
None	1.3	5.2	4.4	4.2	3.3	Disc. at 75 cycles			
.0066% Aluminum Powder	2.5	5.1	5.2	5.1	4.8	4.8	4.8	4.7	4.4
LOSS IN WEIGHT OF PRISMS DURING FREEZING AND THAWING—%									
None	1.3	0	1	1	4	Disc. at 75 cycles			
.0066% Aluminum Powder	2.5	0	0	0	0	1	1	2	5

*Approximate air content of hardened concrete.

in the molds. In this case the mechanical agitation during mixing had nothing to do with void formation, the gas causing the voids being produced by chemical reaction.

The commercial wetting agent was a sulfated fatty alcohol which produced foaming during agitation of the concrete in the mixing process, thereby entrapping air in the concrete.

The air-entraining portland cement was a commercial portland cement ground with .05 per cent Vinsol resin. It is assumed that when mixed with water the alkali hydroxides from the hydrolysis of the cement minerals form sodium or potassium resinates. These are soluble soaps which cause foaming during the mixing operation with the result that air is trapped in the concrete. The cement without addition, Table 1 (a), was a commercial portland cement from the same plant as the cement ground with Vinsol resin.

The aluminum powder, Table 1(b), which was ground with the clinker, was of the polished type. After mixing the concrete, the aluminum reacts with the calcium and alkali hydroxides produced by the hydrolysis of the cement minerals, to form hydrogen gas which is trapped in the concrete. Much of the gas was generated after the concrete was placed in the molds.

It is evident from the expansions, changes in Young's modulus and losses in weight of the concrete prisms during 200 or 300 cycles of freezing and thawing while immersed in tap water, that each of the four methods used to increase the air content produced concrete much superior in resistance to that without the air-entraining additions.* These results point strongly to the conclusion that it is the formation of well-distributed and disconnected air voids in the concrete which is largely responsible for the greatly increased durability and not the material itself which was used to entrain the air.

Combined freezing and thawing and permeability tests with air-entraining portland cements

Table 2 presents the results of a few tests made to determine the effect of freezing and thawing on the permeability of concrete containing cements ground in the laboratory with .05 per cent tallow and .05 per cent Vinsol resin. The specimens were concrete discs, 6 in. in diameter and 3 in. thick. After one day in the molds the discs were cured 6 days in water at 70 F. and 6 days in air of laboratory when they were subjected to a water pressure of 80 psi and the water passing through the specimen (termed "leakage" in Table 2) determined during a 72-hr. period. After this initial permeability test, the discs were stored in air for 7 days and

*An exception occurs in tests for resistance to surface scaling in which aluminum powder has been found to be less effective in increasing the resistance of the concrete than Vinsol resin, tallow and other air-entraining agents.

TABLE 2—RESULTS OF COMBINED FREEZING AND THAWING AND PERMEABILITY TESTS OF CONCRETE

Series J-318

Cement: Laboratory mixture of 4 portland cement (Type I) clinkers, Lot 14895, ground without addition and with .05 per cent tallow or .05 per cent Vinsol resin by weight.
Concrete: 1-2.4-3.4 mix by weight except for Ref. No. 16 which was 1-2.55-3.7 mix by weight.
Aggregate: Cow Bay sand and gravel graded from 0 to ¾-in.
Values of permeability and loss in weight are the average of tests made on 3 discs unless otherwise noted.
Values of air content are for the freshly-mixed concrete.

Ref. No.	ADDITION		DETAILS OF CONCRETE				
	Kind	% by Wt. of Cement	Cement Content, sk. per cu. yd.	Water Content, gal. per sk., Net	Slump, in.	Weight, lb. per cu. ft.	Air Content, %
4	None.....	.00	5.8	6.2	4.3	148.4	1.0
16	"	.00	5.4	6.3	3.5	148.5	1.3
5	Tallow.....	.05	5.5	5.9	3.5	140.4	6.9
6	"	.05	5.6	5.6	2.3	143.1	5.5
7,17	Vinsol Resin.	.05	5.4	5.4	2.7	138.0	9.1

Ref. No.	COMBINED FREEZING AND THAWING AND PERMEABILITY TESTS OF 3 BY 6-IN. CONCRETE DISCS											
	Leakage in gal./sq. ft. during 24 hr. under 80 lb./sq. in. water pressure after indicated cycles of F. & T. in Tap Water					Per cent Loss in Weight during Indicated Cycles of Freezing and Thawing in a 10 per cent Calcium Chloride Solution, following 130 Cycles of Freezing and Thawing in Tap Water						
	0	30	60	100	130	10	20	40	60	80	130	150
4	.00	.11	.73	1.48	*	13.6	26.7	40.4	Discontinued at 40 cyc.			
16	.00	.02	.48	.81	*	9.2	20.1	73.2		"	"	" "
5	.00	.00	.00	.00	*	0.1	0.1	0.2	0.5	0.9	3.7	6.7
6	.00	.00	.00	.00	*	0.0	0.0	0.2	0.6	0.7	4.3	7.3
7, 17†	.00	.00	.00	.00	*	0.1	+0.1	0.0	0.0	0.1	1.5	2.9

*Leakage not determined beyond 100 cycles of freezing and thawing in tap water. Losses in weight during freezing and thawing in a 10 per cent solution of calcium chloride are based on the weight of the specimens after 130 cycles of freezing and thawing in tap water.
†Values are average of tests on 6 discs.

then given 10 cycles of freezing and thawing in tap water following which they were given a similar permeability test for 24 hr. This test procedure, a 7-day air-storage treatment, 10 cycles of freezing and thawing in tap water followed by a 24-hr. permeability test, was repeated ten times giving 100 cycles of freezing and thawing. Then the discs, without being further subjected to the permeability test, were given an additional

30 cycles of freezing and thawing in tap water and 40 to 150 cycles in a 10 per cent calcium chloride solution. Losses in weight were determined during the test in calcium chloride. Thus these discs received a total of from 170 to 280 cycles of freezing and thawing before the tests were discontinued.

It will be seen from Table 2 that the discs made with the air-entraining cements showed no leakage during 100 cycles of freezing and thawing in tap water. They also showed low losses in weight during 150 cycles in the 10 per cent calcium chloride solution following the 130 cycles in tap water. In contrast to these results the discs containing the cement ground without tallow or Vinsol resin showed some leakage after 100 cycles of freezing and thawing in tap water and lost as much as 73 per cent in weight during 40 cycles of freezing and thawing in the 10 per cent calcium chloride solution. These data are in complete agreement with those presented in Table 1 and support the belief that the increased air content of the concrete produced by the air-entraining additions is probably the most important single factor responsible for its greatly improved resistance to freezing and thawing.

Freezing and thawing tests with commercial air-entraining portland cements

It has just been shown that when the air voids of a concrete mix are increased over those normally present in the mix its resistance to freezing and thawing is increased to a surprising degree. Since increases in air content cause reductions in strength the question naturally arises as to just how much of an increase in air content is necessary to obtain high resistance to freezing and thawing without reducing strength unduly. To obtain information on this point, tests were made with 13 air-entraining portland cements manufactured for two large experimental highway projects constructed in New York State. Eight of these cements were ground with .05 per cent of beef tallow and five with .05 per cent Vinsol resin. Included in the tests were normal portland cements from the same plants that furnished the air-entraining products. Each of the air-entraining cements was tested alone and also when blended in 2 or 3 different proportions with its companion cement ground without tallow or Vinsol resin. This procedure gave concretes having air contents ranging from that given by the normal cement to that of the cement ground with .05 per cent of the air-entraining addition. Supplementing these tests similar blends were made with cements ground in the laboratory with tallow and Vinsol resin, from a mixture of equal parts of four normal clinkers. These clinkers were from the plants from which the four cements comprising the "laboratory mixture" used by this laboratory have been obtained for over 25 years. Concrete prisms from the different cements were subjected to freezing and thawing tests, and their resistance

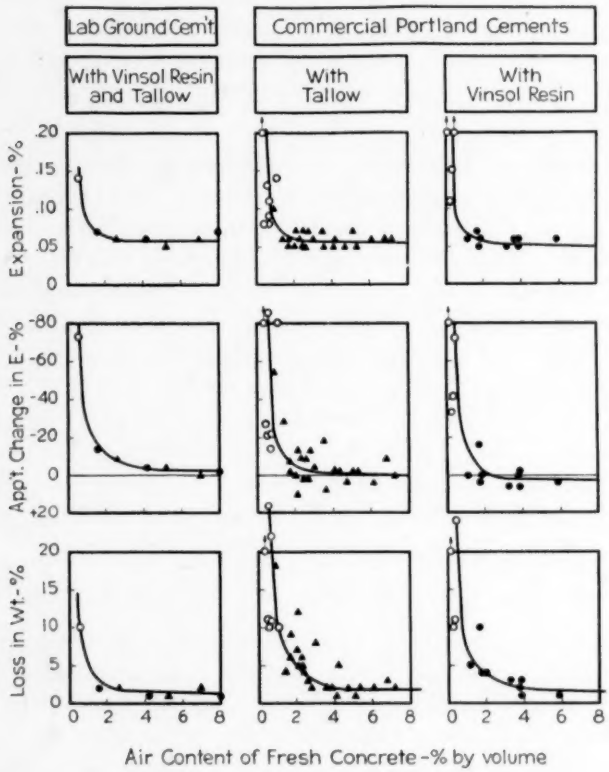

Fig. 1—Results of freezing and thawing tests of 3x3x11¼-in. concrete prisms containing cements ground without and with tallow or Vinsol resin.

Plotted values are for 225 cycles of freezing and thawing (2 cycles per day).
Legend: ° **Concrete made with cements without addition.**
▲ **Concrete made with cements ground with tallow used alone and blended with cement without tallow.**
• **Concrete made with cements ground with Vinsol resin used alone and blended with cement without Vinsol resin.**

Concrete: Cement content 6.3 sk. per cu. yd., slump 2 to 4 in. After one day in molds prisms cured in water for 13 days, 1 month in air of laboratory and 2 to 5 months in sealed metal cans. Prisms then soaked in water for 7 days and frozen and thawed immersed in a 10 per cent calcium chloride solution for 125 cycles. Prisms given an additional 125 cycles while immersed in tap water unless discontinued before they had received a total of 250 cycles.

determined from measurements of linear expansion, reduction in modulus of elasticity, and loss in weight during the test. The results for 225 cycles of freezing and thawing are presented in Fig. 1.

The diagrams in Fig. 1 are similar to many others that have been obtained in tests of different air-entraining cements. It is clear from the various curves that the cements ground with tallow and Vinsol resin gave equally good results. It is also clear that when the air content was increased only a relatively small amount over that of the concretes made

with the normal portland cements, a very great improvement in resistance to freezing and thawing was obtained. This is indicated by the low expansion, small reduction in modulus of elasticity and low loss in weight for air contents slightly above those obtained with the normal portland cements which were generally less than about 1 per cent. Concretes having air contents of about 3 per cent (an increase of about 2 percentage points over the air content of the normal cement concrete) showed about as good resistance as those with higher air contents. Air contents in excess of about 5 per cent should be avoided because, as will be shown later, they are accompanied by a considerable falling off in strength, without any compensating gain in resistance to freezing and thawing.

In addition to the freezing and thawing tests, other prisms in this series after 13 days' storage in water were measured for shrinkage, during storage in air at a temperature of 75 F. and 50 per cent relative humidity, over a period of 2 years. The expansions of companion prisms stored in water for 2 years were also measured. These measurements showed that the tallow and Vinsol resin had little, if any, effect either on the shrinkage of the concrete during storage in air or on its expansion during storage in water.

Modulus of elasticity determinations on the prisms by the sonic method made just prior to the freezing and thawing test, showed that there was a reduction in modulus of elasticity with increase in air content. The decrease in modulus amounted to about 3 per cent for each percentage point increase in air content of the fresh concrete.

3—TESTS OF CONCRETE SLABS AND CORES FROM EXPERIMENTAL ROADS CONSTRUCTED WITH AIR-ENTRAINING PORTLAND CEMENTS

Maine experimental road project

The curves in Fig. 2 are based on tests of 3 by 6 by 15-in. slabs and 5½-in. diameter cores from one of the first large experimental road projects constructed with air-entraining portland cement. This project was built in the State of Maine in 1939. Several of the slab specimens from this project were tested for resistance to surface scaling by the procedure described previously and designated as the "surface scaling test." Other slab specimens were tested for resistance to freezing and thawing while immersed in tap water. Top halves of the cores were frozen and thawed in a 10 per cent calcium chloride solution. The portland cement (Type I) and the air-entraining cements ground with .03 per cent and .05 per cent Vinsol resin in these tests were from the same plant.

In all of the tests represented in Fig. 2 the specimens containing the cement ground with Vinsol resin showed outstanding resistance as compared with that of the specimens containing cement without the air-entraining addition. The surfaces of the specimens with the air-entrain-

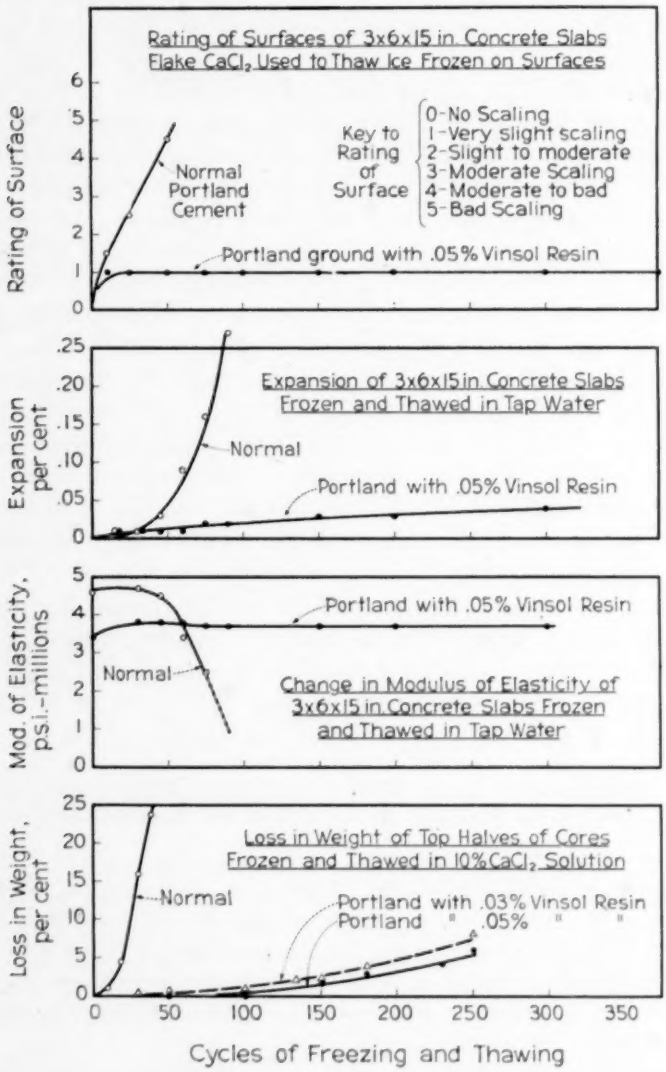
Rating of Surfaces of 3x6x15 in. Concrete Slabs
Flake $CaCl_2$ Used to Thaw Ice Frozen on Surfaces
Rating of Surface
Key to Rating of Surface
0-No Scaling
1-Very slight scaling
2-Slight to moderate
3-Moderate Scaling
4-Moderate to bad
5-Bad Scaling
Normal Portland Cement
Portland ground with .05% Vinsol Resin
Expansion per cent
Expansion of 3x6x15 in. Concrete Slabs
Frozen and Thawed in Tap Water
Normal
Portland with .05% Vinsol Resin
Mod. of Elasticity, p.s.i.-millions
Portland with .05% Vinsol Resin
Normal
Change in Modulus of Elasticity of
3x6x15 in. Concrete Slabs Frozen
and Thawed in Tap Water
Loss in Weight, per cent
Loss in Weight of Top Halves of Cores
Frozen and Thawed in 10% $CaCl_2$ Solution
Normal
Portland with .03% Vinsol Resin
Portland " .05% " "
Cycles of Freezing and Thawing

Fig. 2—Results of freezing and thawing tests of concrete slabs and cores from Maine experimental road project FA 118 AB.

Concrete: Cement content 6½ sk. per cu. yd., slump 2 to 4 in.

Slab specimens made from concrete as it was placed on project, cured 1 day in molds covered with wet burlap, and on pavement under wet hay for 6 days, then removed to a field shack for a few days before shipping to Chicago. Slabs tested at age of 28 to 40 days.

Slabs frozen and thawed in tap water were immersed in water for 4 days before tests were begun.

Slabs for scaling tests were provided with mortar dykes around top surfaces at least 3 days prior to freezing and thawing. The scaling test consisted in alternately freezing a ¼-in. layer of ice on the top surface and then thawing the ice with flake calcium chloride applied in an amount equivalent to 2.4 lb. per sq. yd.

Core specimens were the top halves of 5½-in. diameter cores which were immersed in water for 4 days before freezing and thawing in a 10 per cent calcium chloride solution. Approximate age of cores at time of test was 7 months.

All specimens given 1 cycle of freezing and thawing per day.

ing cement resisted scaling to a remarkable degree, showing only very slight scaling during 375 cycles of the severe treatment in the surface scaling test. The photographs at the top of Fig. 4 show the condition of the surfaces of typical slabs at the completion of the scaling tests.

The cores representing the two air-entraining cements ground with .03 per cent and .05 per cent Vinsol resin (lower diagram of Fig. 2) also resisted to a high degree the severe freezing and thawing cycles in a 10 per cent calcium chloride solution and showed no important differences in weight losses during 250 cycles. These results are all the more significant because unfrozen cores representing the cement containing .05 per cent Vinsol resin averaged 43 per cent lower in strength at 8 months than those for the cement without addition. The core strengths for the cement containing .03 per cent Vinsol resin averaged 14 per cent less than those for the cement without addition. The approximate air contents of the fresh concrete represented by these cores were 1.0 per cent for the normal cement, 4.5 per cent for the cement ground with .03 per cent Vinsol resin and 9.0 per cent for the cement ground with .05 per cent Vinsol resin. Because of the high air content obtained with the latter cement, cement ground with only .03 per cent of Vinsol resin was used in the construction of the second portion of this experimental project.

Tests of cores from experimental road projects

In addition to the cores from the Maine Project just discussed, cores from several other experimental roads were similarly tested. Relationships between losses in weight and cycles of freezing and thawing in a 10 per cent calcium chloride solution for concrete cores representing the normal and air-entraining portland cements used in the construction of six of these experimental road projects are given in Fig. 3. For each normal cement used there was a corresponding air-entraining cement from the same plant. Cores for 17 normal portland cements and 17 air-entraining portland cements are represented in this figure. In no case did the cores containing the air-entraining cements fail to show a very substantial improvement in resistance as compared to those containing the cements without the air-entraining additions.

Condition of specimens from road projects after the surface scaling test

Fig. 4 shows photographs of the top surfaces of typical slabs containing normal portland and air-entraining portland cements from 4 experimental projects after they had been subjected to as many as 375 cycles of the surface scaling test. These photographs speak for themselves. The specimens containing the air-entraining portland cements showed only slight, if any, scaling after as many as 300 to 375 cycles of this severe test, whereas companion specimens without the air-entraining addition showed serious scaling after 40 to 75 cycles. These results are

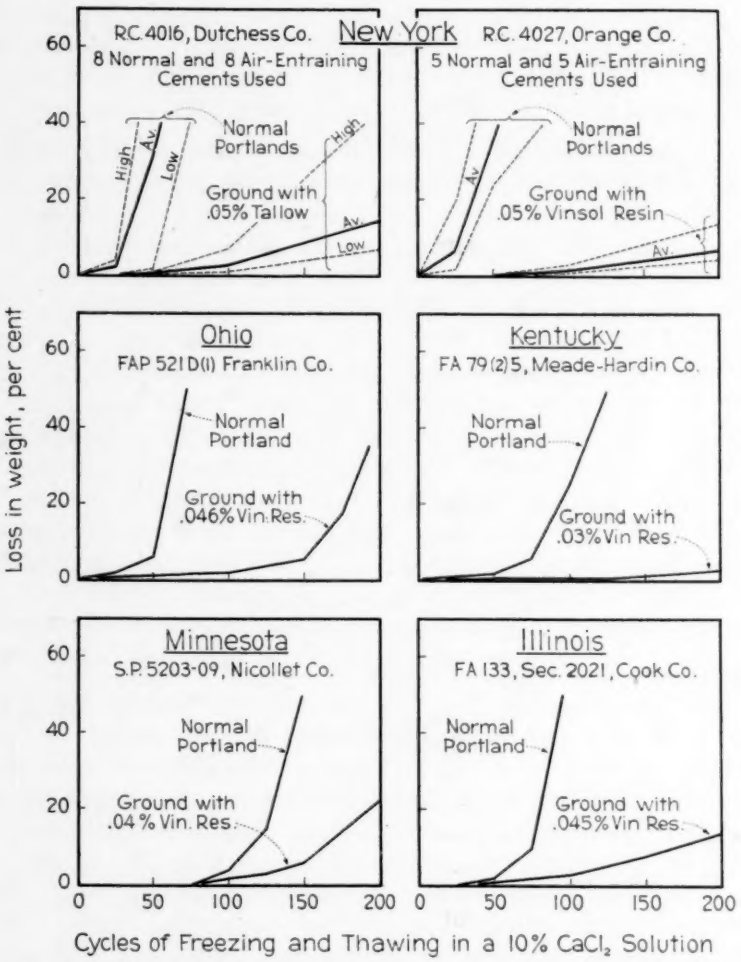

Fig. 3—Results of freezing and thawing tests of concrete cores from six experimental road projects

Cement content of concrete: Approximately 5 sacks per cu. yd. for Minnesota project; for other projects 5¾ to 6½ sk. per cu. yd.

All cores (4¾ or 5½-in. diam.) soaked in water for 4 days prior to freezing and thawing.
Age at test 1½ to 10 months.
Series J322, J323, and J350.

typical of many others obtained during the past 5 years, and are in agreement with the performance of the experimental paving projects constructed with air-entraining portland cements, photographs of portions of the surfaces of two of which are shown in Fig. 5.

4—TESTS OF CONCRETE CONTAINING VINSOL RESIN ADDED IN SOLUTION AT MIXER

In view of the excellent results obtained with Vinsol resin when ground with the cement, and because in some concreting operations certain

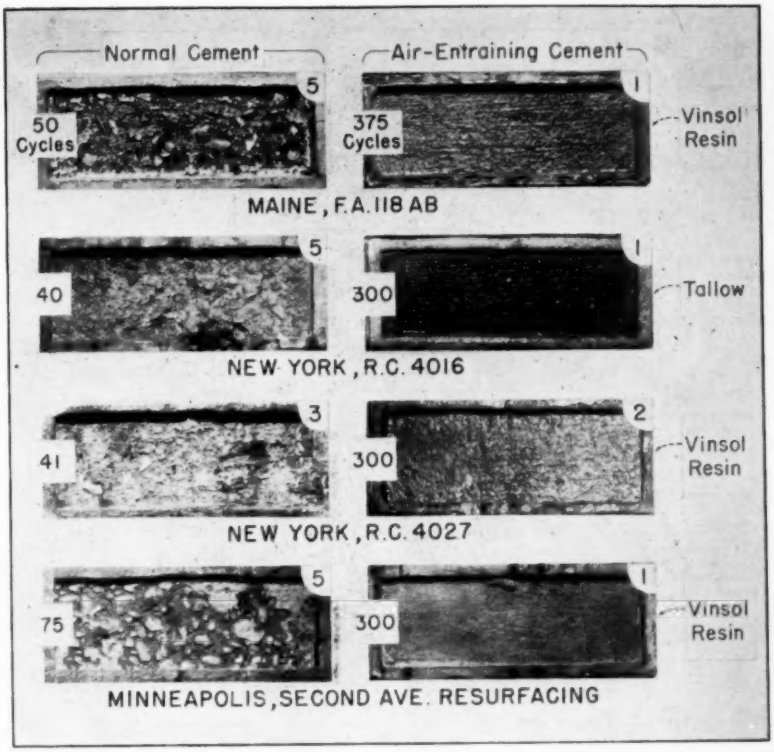

Fig. 4—Surfaces of typical 3x6x15-in. concrete slabs from four experimental road projects after test for resistance to scaling.

Numerals upper right corner of slabs indicate rating of surface:
0—No scaling
1—Very slight scaling
2—Slight to moderate scaling
3—Moderate scaling
4—Moderate to bad scaling
5—Bad scaling

advantages may be gained by introducing the Vinsol resin into the concrete at the time of mixing, extensive studies were made of the resistance to scaling and to freezing and thawing, as well as of other properties of concrete when the Vinsol resin is added in a *NaOH*-water solution at the mixer. Vinsol resin is sold commercially as a powder in which form it does not seem to be very effective in entraining air when added directly to the batch. However, it dissolves readily in cold dilute solutions of sodium hydroxide with the formation of a resin soap (sodium resinate) which is very effective in entraining air in mortar and concrete. When added to the concrete in a *NaOH*-water solution, Vinsol resin is more effective than when ground with the clinker in powdered form. For example, in one case .01 per cent of Vinsol resin (by weight of cement) added in solution at the mixer produced about the same air content as .05 per cent ground with the clinker.

Fig. 5 — Photographs (5a at right; 5b left and right below.) of portions of surfaces of two experimental paving projects.

(a) Resurfacing project on Second Avenue, Minneapolis, Minn., after four winters' exposure to salt action and cycles of freezing and thawing. Lane at left constructed with normal portland cement. Lane at right constructed with air-entraining portland cement ground with .03 per cent Vinsol resin.

(b) Illinois experimental paving project, F. A. 133, Sec. 2021, Archer Avenue, Chicago, after two winters' exposure to salt action and freezing and thawing; at left, north lanes constructed with normal portland, bad surface scaling; at right, south lanes constructed with portland cement ground with .045 per cent Vinsol resin, no scaling.

Sodium resinates made from wood rosin are available commercially in the form of powders, flakes and pastes. These materials may be dissolved in water to yield resin soap solutions similar to those produced by dissolving Vinsol resin or rosin in alkaline solutions. An emulsion containing about 40 per cent of Vinsol resin is also available commercially. Tests with these materials showed that they can be used to entrain air in concrete by adding them directly to the batch.

Table 3 and Fig. 6 and 7 show results of tests of concrete in which the quantity of entrained air was varied by the addition at the mixer

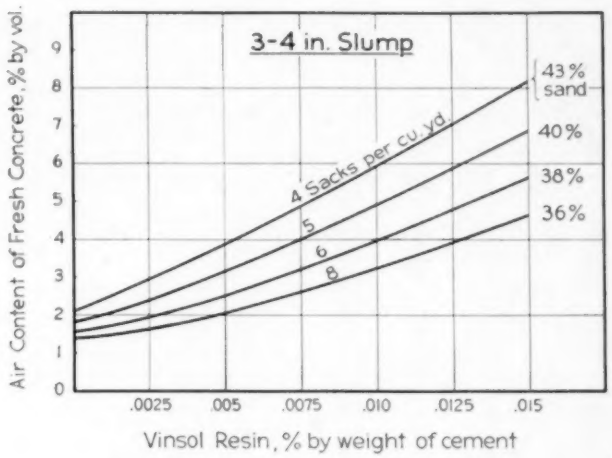

Fig. 6—Effect of amount of Vinsol resin on air content of concrete mixes of constant cement content.

Vinsol resin added at mixer in solution with NaOH and water (1 part Vinsol resin, 0.5 parts NaOH, 43 parts water by weight). Aggregate: Elgin sand and gravel graded from 0 to 1-in.

of different quantities of Vinsol resin in a *NaOH*-water solution consisting of 1 part Vinsol resin, 0.5 parts *NaOH* and 43 parts water by weight. This particular concentration of Vinsol resin was used for convenience in adding the soap solution to the batch. The ratio of *NaOH* to Vinsol resin was higher than needed but was selected before experiments had shown that only 0.15 parts of *NaOH* to 1 part of Vinsol resin was all that was required for ready saponification of the resin.*

For convenience in measuring the quantity of solution required for a batch the constituent materials were used in the following amounts:

45.4 grams of Vinsol resin,
22.7 grams of *NaOH*,
Sufficient water to make 2000 ml. of solution.

The amount of this solution to be added for each pound of cement in the batch, in order to obtain various percentages of Vinsol resin by weight of cement, was measured on the following convenient basis:

Per cent Vinsol Resin by Weight of Cement	Amount of Solution Required per Lb. of Cement—ml.
0.005	1.0
0.0075	1.5
0.010	2.0
0.015	3.0

*Theoretically, .07 parts of solid *NaOH* are required to saponify one part of Vinsol resin. However, the rates of solution and saponification of resins are increased when the alkali concentration is greater than that required for complete saponification and it was found preferable to use about 0.15 parts of *NaOH* to 1 part of resin in 10 or more parts of water. Excess of *NaOH* over that required to dissolve the resin serves no useful purpose and adds to the cost. Hence the quantity of *NaOH* should be the least amount which will completely dissolve the resin in a short period of time. *KOH* behaves similarly to *NaOH* in the saponification of resins but it is preferable to use *NaOH* because of its lower cost.

TABLE 3 — TESTS OF CONCRETE CONTAINING VINSOL RESIN ADDED IN A NaOH-WATER SOLUTION AT MIXER

SERIES 303

Mixes designed to have cement contents of 4, 5, 6 and 8 sacks per cu. yd.

Cement: Lot 16436, laboratory mixture consisting of equal parts of 4 brands of commercial portland cements (all of Type I).

Aggregate: Elgin sand graded from 0 to No. 4 sieve, and Elgin gravel graded as follows: 25 per cent, 4—⅜-in.; 50 per cent, ⅜-¾-in.; 25 per cent, ¾-1-in.

Vinsol resin was added at mixer in a solution consisting of 1 part Vinsol resin, 0.5 parts *NaOH*, and 43 parts water by weight.

All specimens in molds 1 day then in moist room until tested.

W/C ratio is the total water less absorption of the aggregate at 10 minutes.

Except as noted each value for air content is average of 6 tests and each strength value is average of 3 or 6 tests.

In tests for modulus of rupture prisms were loaded at center of 10-in. span.

Ref. No.	Mix by Weight	Sand, % by Wt.	Vinsol Resin, % by Weight Cement	Fresh Concrete: W/C gal. per sk.	Cement Content, sk. per cu. yd.	Slump, in.	Unit Wt. lb./ cu. ft.	Air Content, %	Modulus of Rupt. of 3x3x11¼-in. Conc. Prisms, psi: 28d.	ly.	Compressive Strength, lb. per sq. in. — 3-in. Modified Cubes: 28d.	ly.	6 by 12-in. Concrete Cylinders: 1d.	3d.	7d.	28d.	3m.	ly.
NOMINAL SLUMP 3 TO 4-IN.																		
101	1-1.46-2.59	36	0	4.07	7.99	3.1	152.1	1.3	1065	1230	9250	9800	2000	4540	6310	8040	8340	9420
102	1-1.44-2.56	"	.005	4.06	8.00	3.0	150.8	2.0	1000	1165	8660	9450	1990	4480	5940	7430	8490	9280
103	1-1.43-2.54	"	.0075	4.05	8.00	3.1	149.9	2.6	1045	1205	8760	9170	1920	4270	5780	7150	8130	8860
104	1-1.42-2.52	"	.010	4.03	8.00	3.1	149.0	3.2	950	1130	8180	9150	1860	4270	5240	7060	8060*	9040
105	1-1.40-2.48	"	.015	4.03	7.97	3.1	146.8	4.6	925	1025	7370	8420	1700	3940	5010	6080*	7440	8380
106	1-2.20-3.59	38	0	4.90	5.99	2.8	152.3	1.4	915	1115	8560	9270	1280	3720	5290	6950	7630	8760
107	1-2.16-3.52	"	.005	4.79	6.03	2.7	150.8	2.4	945	1080	7820	8400	1400	3460	5310	6900	7550	7950
108	1-2.14-3.49	"	.0075	4.73	6.03	2.7	149.5	3.3	870	1115	7970	8170	1340	3500	4800	6280	7500*	7930
109	1-2.12-3.45	"	.010	4.68	6.04	2.6	148.4	4.1	875	1045	7690	8100	1290	3380	4890	6500*	6650	7680*
110	1-2.08-3.38	"	.015	4.55	6.07	2.5	146.7	5.4	865	1085	6840	7290	1250	3180	4690	5960	6420*	7270

111	1-2.82-4.23	40	0	5.72	5.03	2.7	151.5	1.7	875	1050	7210	7800	870	2690	4500	6280	6740*	7350
112	1-2.78-4.17	"	.005	5.59	5.02	2.7	149.5	3.1	860	985	6700	7290	900	2700	4320	6050	6860	7040
113	1-2.76-4.14	"	.0075	5.52	5.02	3.0	148.2	4.0	810	970	6700	7060	870	2710	4230	5890	6390	7040
114	1-2.74-4.11	"	.010	5.45	5.00	3.2	146.8	5.0	725	925	6340	6610	830	2560	4050	5570	6210	6530
115	1-2.70-4.05	"	.015	5.30	4.98	3.2	144.3	6.8	825	910	5860	6280	780	2080	3660	5040	5560	5990
116	1-3.89-5.16	43	0	7.51	3.97	2.3	149.9	2.0	750	780	5140	5220	420	1620	2660	4340*	5080	5250
117	1-3.82-5.07	"	.005	7.35	3.96	3.8	147.0	3.9	725	760	4890	5290	420	1670	2650	4320	4910	5000*
118	1-3.78-5.02	"	.0075	7.24	3.96	4.4	145.8	4.8	710	770	4690	5110	410	1610	2670	4260	4860	4890
119	1-3.75-4.97	"	.010	6.82	3.98	3.5	144.6	6.0	665	765	4650	4910	450	1620	2700	4140	4650	4930
120	1-3.68-4.87	"	.015	6.41	3.99	3.4	142.1	8.0	660	770	4250	4650	440	1530	2440	3880	4380	4530

NOMINAL SLUMP 6 TO 7-IN.

121	1-1.44-2.56	36	0	4.32	7.99	6.2	151.2	1.2	990	1125	8920	8800	1690	4240	5750	7290*	8170	9210
122	1-1.42-2.52	"	.005	4.32	8.00	6.0	149.7	2.1	955	1055	8250	9210	1680	4000	5230	6780	7660	8800
123	1-1.40-2.50	"	.0075	4.31	8.00	6.1	148.5	2.8	965	1090	8290	8940	1660	3880	5160	6670	7830	8090
124	1-1.39-2.48	"	.010	4.29	7.98	6.0	147.3	3.6	875	1055	7960	8150	1630	3830	5260	6750	7500*	8060
125	1-1.37-2.43	"	.015	4.27	7.95	5.9	144.6	5.3	855	1115	7200	7700	1520	3470	4860	6070	7080	7670
126	1-2.19-3.56	38	0	5.31	5.97	6.4	151.6	1.1	920	1130	7640	8450	1010	3050	4880	6440	7510	7680
127	1-2.14-3.48	"	.005	5.22	6.01	6.4	149.8	2.3	915	1065	7150	8240	1020	2960	4710	5980	7000	7790*
128	1-2.11-3.44	"	.0075	5.18	6.02	6.7	148.3	3.3	885	1100	7200	8060	1020	2960	4610	6000*	6920	7290
129	1-2.08-3.40	"	.010	5.13	6.01	6.9	146.8	4.3	820	1070	6490	7390	980	2890	4390	5770	6810	6910
130	1-2.03-3.32	"	.015	5.04	6.01	6.7	143.6	6.4	800	910	5780	6170	920	2600	4020	5100	5900	6210
131	1-2.82-4.23	40	0	6.13	5.01	5.4	151.4	1.2	855	1030	6830	7400	770	2440	4040	6060	6630	6990
132	1-2.76-4.14	"	.005	5.97	5.02	5.7	149.0	2.9	840	955	6450	6930	730	2430	3820	5520	6250	6480
133	1-2.73-4.09	"	.0075	5.88	5.03	6.3	147.7	3.7	815	945	6250	6640	750	2350	3860*	5460	6140	6300
134	1-2.70-4.05	"	.010	5.79	5.02	6.3	145.9	5.0	765	940	5690	6400	740	2230	3710	5060	5850	6120
135	1-2.64-3.96	"	.015	5.61	5.00	6.3	142.7	7.2	750	840	5020	5380	690	1910	3370	4660	5250	5530
136	1-3.85-5.10	43	0	8.00	3.99	6.7	149.7	1.4	675	790	4510	4920	380	1450	2470	4130	4710	4550
137	1-3.77-5.00	"	.005	7.65	4.01	6.8	147.6	3.1	705	750	4300	4820	410	1550	2660	4230*	4830	5060
138	1-3.73-4.95	"	.0075	7.48	4.02	7.0	146.0	4.2	695	835	4320	4730	410	1530	2600	4060	4710	4680
139	1-3.69-4.90	"	.010	7.30	4.01	7.0	144.3	5.5	600	770	4100	4450	400	1450	2540	3960	4410	4390
140	1-3.61-4.79	"	.015	6.94	4.00	7.0	140.9	8.0	625	715	3760	3830	360	1320	2330	3470	4080	3970

*Average of 2 tests.

Relation between quantity of Vinsol resin added in NaOH-water Solution and Air content of concrete

The curves in Fig. 6 show relationships between the per cent of Vinsol resin by weight of cement (added in a *NaOH*-water solution at mixer) and the air content of freshly-mixed concrete, for mixes designed to have cement contents of 4, 5, 6 and 8 sacks per cu. yd. and a slump of 3 to 4 in. For each cement content there was included a mix without Vinsol resin and 4 additional mixes each containing a different amount of Vinsol resin. The percentage of sand was maintained constant in the mixes of a given cement content (Table 3).

It is apparent from Fig. 6 that for mixes of constant cement content and percentage of sand, the air content increased regularly with increase in the percentage of Vinsol resin introduced into the concrete. As the cement content of the concrete is increased, the greater is the amount of Vinsol resin required to produce a given air content. For example, concrete containing 4 sacks per cu. yd. required .0025 per cent Vinsol resin by weight of cement to produce an air content of 3 per cent while .009 per cent Vinsol resin was required to produce the same air content in an 8-sack per cu. yd. concrete.

In these tests the mix proportions (including the per cent of sand) and the quantity of mixing water were adjusted to compensate for the tendency of the increased amounts of admixture to increase the air content and slump. These adjustments were considerable in the case of the mixes of low cement content. The decrease in percentage of sand as the cement content increased was from 43 to 36 per cent. Therefore part of the decrease in air content which occurred with increase in cement content is attributable to the decrease in the percentage of sand. It was found in another series of tests for concrete of constant cement content and slump, with and without Vinsol resin, that when the percentage of sand was decreased the air content also decreased, the rate of decrease in air content being somewhat greater when Vinsol resin was present than when it was absent. Decreasing the percentage of sand also tends to decrease the water content of the concrete somewhat and this in turn tends to increase strength. Reductions in percentage of sand to compensate for increased fatness of the mix when air-entraining cements or additions are used, should be governed by direct observations of the placeability of the concrete and the absence of honeycomb.

From the data presented in Fig. 6 it is apparent that the amount of air entrained in a concrete mix may be readily controlled merely by changing the percentage of Vinsol resin added. The ability to control the amount of entrained air by the percentage of Vinsol resin added in the form of soap solution may at times be of considerable advantage since the air content for any given set of conditions can be maintained

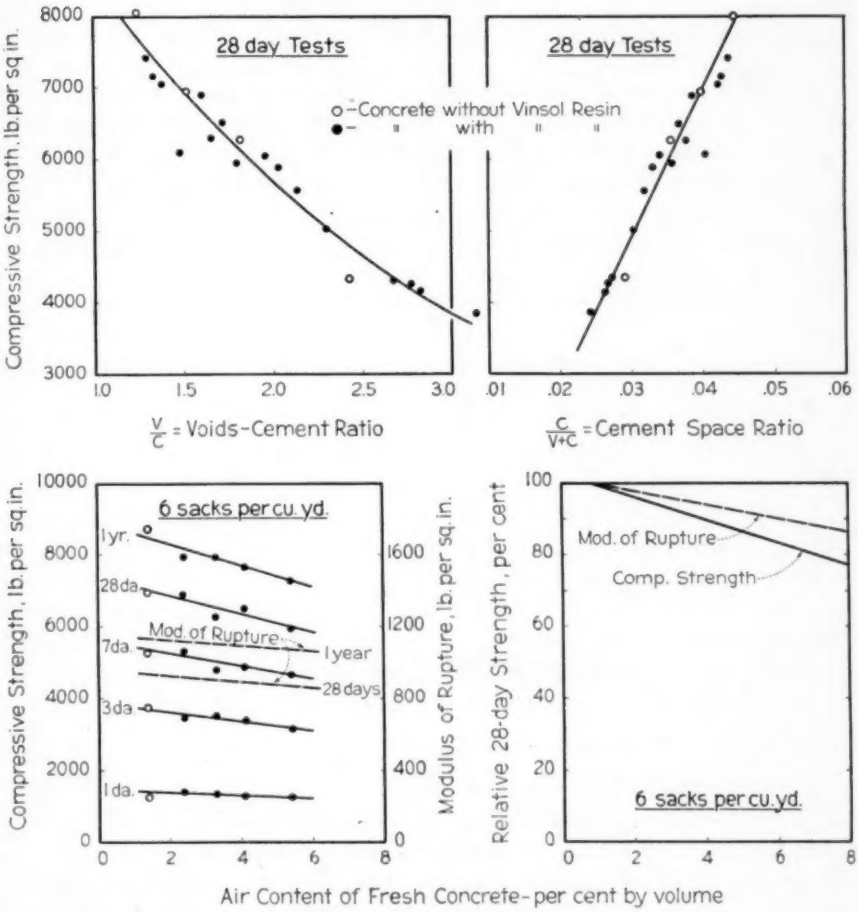

Fig. 7—Strength relations for concrete containing Vinsol resin added in a NaOH-water solution at mixer.

Plotted compressive strengths are the average for three 6x12-in. concrete cylinders; plotted values of modulus of rupture are the average for three 3x3x11¼-in. concrete prisms loaded at center of 10-in. span; Aggregate: Elgin sand and gravel graded from 0 to 1-in.; Cement content: 4, 5, 6 and 8 sk. per cu. yd. unless otherwise noted; Slump: 3 to 4 in.; Specimens cured in moist room, tested damp.

at the desired amount by adjusting the quantity of solution added to the batch. As will be shown later only .005 to .01 per cent of Vinsol resin is required when added in solution during mixing, to markedly increase the resistance of concrete to surface scaling and to freezing and thawing.

Strength relations for concrete containing Vinsol resin added in a NaOH-water solution at mixer

Before presenting other features of the tests of concrete containing Vinsol resin added in solution, the effect on strength of increasing the

air content of concrete above that normally obtained when no addition is used, will be discussed.

In Fig. 7 are four diagrams based on the same group of tests (Table 3) as those presented in Fig. 6. The two lower diagrams show relationships between the air content of the concrete and the resulting compressive strength and modulus of rupture for moist-cured specimens. The two upper diagrams show relationships between the 28-day compressive strength of moist-cured 6 by 12-in. concrete cylinders and the voids-cement ratio (V/C), and the cement-space ratio $\left(\frac{C}{V+C}\right)$. The ratios V/C and $\frac{C}{V+C}$ are those used by Talbot and Richart over 20 years ago in discussing relationships between strength and the voids in concrete made without air-entraining additions.* In these ratios, which are by absolute volume, the term "C" represents the absolute volume of cement in a unit volume of concrete. The term "V" represents the total voids in a unit volume of concrete—that is, the absolute volume of the air voids plus the absolute volume of the water. Thus the term "V" takes into account the effect of both the air voids and the water in a concrete mix, on the resulting strength. If the air voids are low and relatively constant, as is the case for plastic mixes without air-entraining admixtures, the ratio V/C is equivalent to the water-cement ratio by absolute volume.

It is seen from the relationship between voids-cement ratio and strength (upper left-hand diagram in Fig. 7) that the greater the voids, "V", (air plus water) for a given cement content, the lower is the strength. These same data were used to plot the upper right-hand diagram in Fig. 7 which shows the direct relationship between 28-day compressive strength and the cement-space ratio $\left(\frac{C}{V+C}\right)$. These relationships are similar to those pointed out by Talbot and Richart† for concrete made without air-entraining additions. They indicate that if strength is to be maintained when air-entraining additions are employed, it is necessary to compensate for the increase in volume of the air voids of the concrete by increasing the volume of cement or reducing the volume of water, or by a simultaneous increase in cement and decrease in water content. Although the use of the air-entraining addition permits of some reduction in the amount of water required for a given slump, unless the percentage of sand in the mix also is reduced, the reduction in water may not be sufficient

*The Strength of Concrete in Relation to the Cement, Aggregates and Water, by Arthur N. Talbot and Frank E. Richart; Bulletin 137, Univ. of Illinois Engineering Experiment Station, October, 1923; see also Proc. A.S.T.M., v. 21, p. 940, 1921.

†See Fig. 6 and 8 of Bulletin 137, Univ. of Illinois Engineering Experiment Station referred to above.

to maintain the strength and it may be necessary to increase the cement content somewhat. As pointed out previously, reducing the percentage of sand in the mix will aid greatly in maintaining strength through its effect on lowering the water requirements of the mix.

From the lower left-hand diagram in Fig. 7 it is seen that at each age of test the strengths decreased regularly with increase in air content of the fresh concrete, brought about by the addition of increasing amounts of Vinsol resin in solution. The percentage reduction in strength for each percentage point increase in air content is approximately the same for each age of test. The reduction in modulus of rupture with increase in air content is somewhat less than that for compressive strength. This may be seen from the lower right-hand diagram in Fig. 7, which shows the 28-day strengths of concretes of varying air contents expressed as a percentage of the strength of concrete of the same slump and cement content without the air-entraining addition. This diagram indicates a 2 per cent decrease in modulus of rupture and a 3 per cent decrease in compressive strength for each one percentage point increase in air content. These relationships are shown by dash-lines in Fig. 8 which gives similar diagrams for concrete containing air-entraining cements ground with Vinsol resin and tallow.

Fig. 8 was prepared to bring together on a relative basis the data from several series and from field specimens. The solid lines in Fig. 8 represent concretes containing air-entraining portland cements. They are based on tests of 2x2x9½-in., 3x3x11¼-in., or 6x6x22-in. prisms and 2-in., 3-in., or 6-in. modified cubes. The dash-line curves (same as in Fig. 7) are based on tests of 3x3x11¼-in. prisms and 6x12-in. cylinders made with concretes containing Vinsol resin added in a *NaOH*-water solution at the mixer. The solid-line curves indicate that the strength reductions for concrete such as is used in pavements should not exceed about 6 to 13 per cent for modulus of rupture and about 10 to 20 per cent for compression if the air content is kept within a reasonable working range of say 3 to 5 per cent by volume. These values are larger than those indicated by the dash-line curves but seem unimportant in view of the greatly increased resistance to scaling and to freezing and thawing which results from the use of the air-entraining addition.

Included in Fig. 8 are several plotted points showing average relative strengths of beams and cores from several experimental road projects constructed with air-entraining portland cements. These plotted values are in good agreement with the solid-line curves based on specimens made in the laboratory.

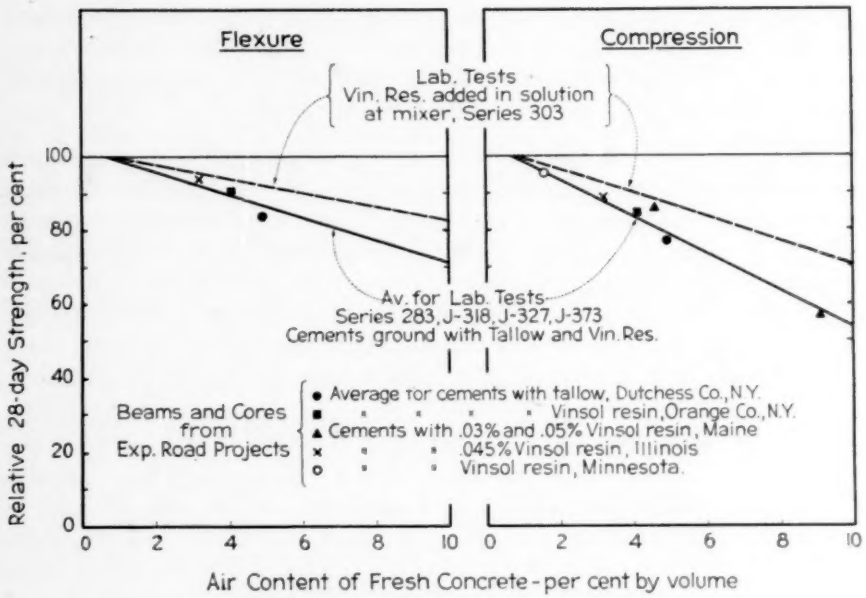
Flexure
Compression
Lab. Tests
Vin. Res. added in solution
at mixer, Series 303
Av. for Lab. Tests
Series 283, J-318, J-327, J-373
Cements ground with Tallow and Vin. Res.
Relative 28-day Strength, per cent
100
80
60
40
20
0
0 2 4 6 8 10
0 2 4 6 8 10
Beams and Cores from Exp. Road Projects
● Average for cements with tallow, Dutchess Co., N.Y.
■ " " " " Vinsol resin, Orange Co., N.Y.
▲ Cements with .03% and .05% Vinsol resin, Maine
× " " .045% Vinsol resin, Illinois
○ " " Vinsol resin, Minnesota.
Air Content of Fresh Concrete - per cent by volume

Fig. 8—Effect of air content on strength of concrete

Solid and dash-line curves are based on tests of moist-cured laboratory specimens including 2x2x9½-in., 3x3x11¼-in. and 6x6x22-in. concrete prisms, 2-in., 3-in., and 6-in. modified concrete cubes, and 6x12-in. concrete cylinders. Cement content 5.4 to 6.5 sk. per cu. yd.; slump 2 to 4 in.

Plotted points represent tests of beams and cores from experimental road projects. Age at test 28 days except for cores from Maine and Minnesota projects which were tested at age of 5 to 8 months.

Air content of concretes without air-entraining additions was approximately 1 per cent.

Freezing and thawing tests of concrete containing Vinsol resin added in a NaOH-water solution at mixer

Comprehensive tests have shown that for comparable air contents the resistance to scaling and to freezing and thawing of concrete containing Vinsol resin added in a *NaOH*-water solution is equivalent to that shown by concrete made with air-entraining cements. Typical results of tests for Vinsol resin added in solution are shown in Fig. 9 and Table 4.

Fig. 9 compares the average expansions, reductions in modulus of elasticity and losses in weight for two groups of 3x3x11¼-in. concrete prisms, each group being made with 14 different fine and coarse aggregate combinations and the same commercial normal portland cement. One group of specimens was made without any air-entraining addition and one group with .01 per cent Vinsol resin by weight of cement added in a *NaOH*-water solution at the mixer. When these tests were discontinued at 150 cycles of freezing and thawing, the specimens with the Vinsol resin addition showed expansions, reductions in modulus of elasticity, and losses in weight that were much lower than for the specimens without

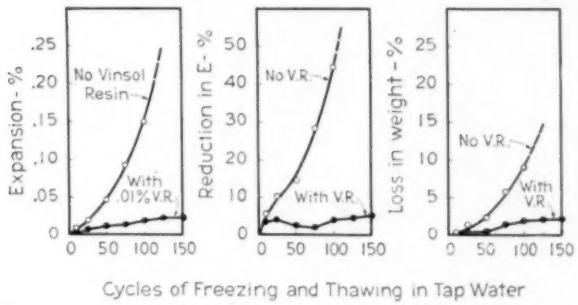

Fig. 9—Results of freezing and thawing tests of 3x3x11¼-in. concrete prisms containing .01 per cent Vinsol resin by weight of cement, added in a NaOH-water solution at mixer.

Curves are based on average results of tests of prisms made with 14 different aggregate combinations using 4 sands and 5 coarse aggregates; 6 prisms for each aggregate combination. Cement content 6 sk. per cu. yd.; slump 2 to 4 in.

Cement: Laboratory mixture of equal parts of 4 brands of Type I portland cement.

Sands: Elgin, Ill.; Cow Bay and Windsor, N. Y. and Dishneau, Mich. graded from 0 to No. 4 sieve.

Coarse aggregates: Elgin, Ill. gravel, Cow Bay, N. Y. gravel, Dishneau, Mich. crushed gravel, N. Y. dolomitic limestone, Wisconsin dolomitic limestone graded from No. 4 sieve to 1-in.

Vinsol resin solution consisted of 1 part Vinsol resin, 0.15 parts NaOH and 43 parts water by weight.

Prisms cured 1 day in molds, 13 days in water at 70°F., 6 months in air of laboratory, then immersed in water for 7 days before starting freezing and thawing tests. During freezing and thawing the specimens were immersed in tap water.

Prisms given 3 cycles of freezing and thawing per day.

the air-entraining addition. These results compare favorably with those shown in Table 1 and Fig. 2.

In Table 4 comparison is made of the average of the surface scaling results obtained in these tests with the average of tests in another series (J-373) where 4 other aggregate combinations were used with 6 pairs of normal and air-entraining portland cements ground with Vinsol resin, each pair of cements being ground from the same clinker. Of chief interest in Table 4 are first, the close similarity in the results obtained for concrete containing Vinsol resin introduced in a *NaOH*-water solution at the mixer and those for concrete made with air-entraining portland cement ground with Vinsol resin, and second, the superior resistance to scaling of the concretes in both series of tests which contained Vinsol resin.

5—TESTS OF CONCRETE CONTAINING BOTH VINSOL RESIN AND CALCIUM CHLORIDE

Effect of adding both Vinsol resin and calcium chloride to concrete

To obtain information on the effect on strength and durability of adding both Vinsol resin and flake calcium chloride to concrete, several groups of tests were made in which various percentages of Vinsol resin and calcium chloride were added directly to the batch during mixing of the concrete. In these tests the Vinsol resin was added in a *NaOH*-water solution in amounts of 0, .005 and .0075 per cent by weight of cement.

TABLE 4—RESISTANCE TO SCALING OF CONCRETE SLABS CONTAINING VINSOL RESIN ADDED IN SOLUTION AT MIXER OR GROUND WITH THE CEMENT

Cement content approximately 6 sacks per cu. yd. Slump 3 ± 1 in.
Key to ratings of surfaces of slabs:
0 = No scaling
1 = Very slight scaling
2 = Slight to moderate scaling
3 = Moderate scaling
4 = Moderate to bad scaling
5 = Bad scaling
Percentages of Vinsol resin are by weight of cement.

Kind of Concrete	Air Content of Fresh Concrete, %	Rating of Surface of 3 by 6 by 15-in. Concrete Slabs after Cycles of Freezing and Thawing Ind.				
		10	25	50	75	100
AVERAGE OF TESTS WITH 14 AGGREGATE COMBINATIONS USING THE SAME (TYPE I) PORTLAND CEMENT—Series J-349						
Concrete without addition	0.8	1	2½	3	4	4½
Concrete containing .01 per cent Vinsol Res. added in *NaOH*-water solution	3.8	½	1	1½	1½	2
AVERAGE OF TESTS WITH 4 AGGREGATE COMBINATIONS USING 6 NORMAL AND 6 AIR-ENTRAINING PORTLAND CEMENTS—Series J-373						
Concrete without addition (average for 6 cements)†	1.0	1½	2½	3½	*	—
Concrete containing cement ground with .04 per cent Vinsol resin (average for 6 cements)†	3.9	1	1	1	1½	1½

*Tests discontinued at 50 cycles.
†Four of Type I, one of Type II and one of Type III.

For each percentage of Vinsol resin, calcium chloride, in percentages ranging from 0 to 4 per cent by weight of cement, was added either in solution with the mixing water, or in dry flake or powdered form. Most tests were made with A. S. T. M. Type I cement but a few were made with Type III cement. For comparison, specimens were also made with A. S. T. M. Types I, II and III cements ground both with and without Vinsol resin. With each of the latter cements, additions of 0 per cent and 2 per cent of dry flake calcium chloride by weight of cement, added directly to the batch at the mixer, were used.

On account of limitations of space, it is not possible to present many of the results of these tests. It may be stated, however, that calcium chloride in amounts up to 2 per cent, when added to the batch, either in solution or in dry form, increased early strengths without decreasing the effectiveness of the Vinsol resin in entraining air and in providing a high degree of resistance to scaling and to freezing and thawing. This was

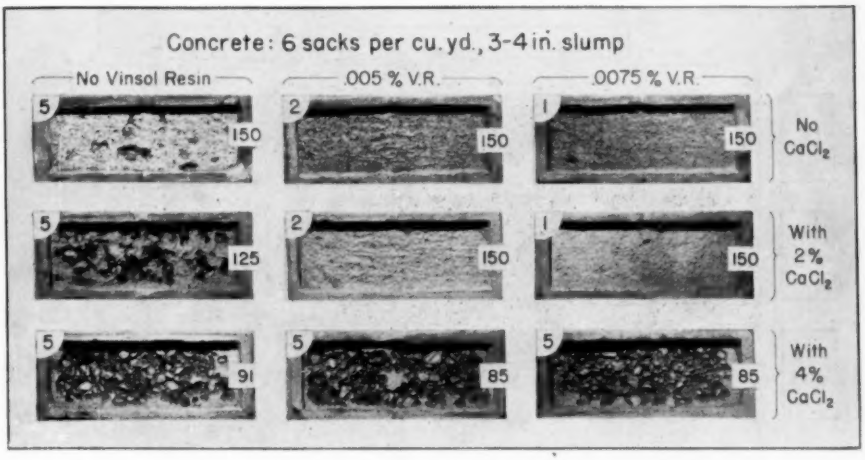

Fig. 10—Surfaces of typical concrete slabs after test for resistance to scaling—Series 310 (different additions of both Vinsol resin and flake calcium chloride).

Vinsol resin added in solution at mixer. (1 part Vinsol resin, 0.15 parts NaOH 45 parts water).
Calcium chloride added in dry flake form at mixer.
Cement: Laboratory mixture of equal parts of 4 brands of Type I Portland cement.
Aggregate: Elgin, Ill. sand graded from 0 to No. 4 sieve and Michigan crushed gravel graded from No. 4 sieve to 1-in.
Slabs 1 day in molds, 6 days in moist room, 19 to 25 days in air, and 4 days in water before testing for resistance to surface scaling.
Numerals in upper left corner of slabs are ratings of surface, those at right are cycles of freezing and thawing. For key to ratings of surface see notes of Fig. 4.

true whether the Vinsol resin was ground with the cement or added in solution at the mixer (Fig. 10 to 12). There was no advantage in using more than 2 per cent of calcium chloride to increase strength at early ages, and with 4 per cent poorer results were obtained in the surface scaling tests than where no calcium chloride was used.

If the amount of calcium chloride is limited to 2 per cent by weight of cement, there appears to be no reason why calcium chloride and Vinsol resin should not be used in the same mix when it is desired to improve early strengths (1 to 3 days) as well as resistance to freezing and thawing and to surface scaling. Each admixture exerts its separate effects on the properties of the concrete, whether the Vinsol resin is ground with the cement or added in solution at the mixer.

Surface scaling of concrete slabs, containing both Vinsol resin and calcium chloride

The photographs in Fig. 10 to 12 visualize the condition of the surfaces of typical concrete slabs made with various combinations of Vinsol resin and calcium chloride, after as many as 150 cycles of the test for surface scaling. In all of these photographs the superior resistance to scaling of the concretes containing either Vinsol resin alone (ground with the cement or added in solution at the mixer), or both Vinsol resin and 2 per cent calcium chloride, is clearly evident. It will be seen from Fig. 10 that the resistance to scaling of concrete was decreased when as much as

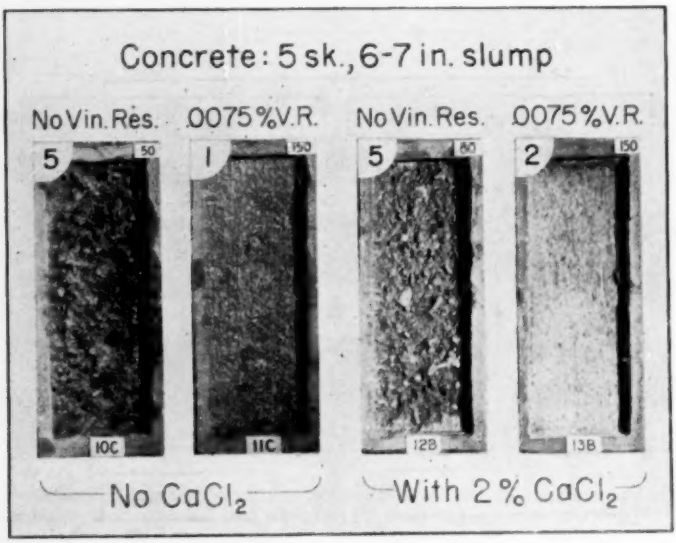

Fig. 11—Surfaces of typical concrete slabs (5 sacks cement per cu. yd., 6 to 7-in. slump) after test for resistance to scaling—Series 310

Vinsol resin added in solution at mixer. (1 part Vinsol resin, 0.15 parts NaOH and 45 parts water).
Commercial calcium chloride added in dry flake form at mixer.
Cement: Laboratory mixture of equal parts of 4 brands of Type I Portland cement.
Aggregate: Elgin, Ill. sand graded from 0 to No. 4 sieve and Michigan crushed gravel graded from No. 4 sieve to 1-in.
Slabs 1 day in molds, 6 days in moist room, 19 to 25 days in air, and 4 days in water before testing for resistance to surface scaling.
Numerals at upper left corner of slabs are ratings of surface, those in upper right corner are cycles of freezing and thawing. For key to ratings of surface see notes of Fig. 4.

4 per cent of calcium chloride was used. The slabs shown in Fig. 12 were made with Type I cements. Similar results were obtained with the slabs containing 0 and 2 per cent calcium chloride that were made with the Types II and III portland cements ground with and without Vinsol resin.

CONCLUDING REMARKS

The results obtained with air-entraining materials, either when ground with the cement or when added at mixer, have consistently shown that they improved to a marked degree the resistance of the concrete to the surface scaling test and to freezing and thawing in tap water or in a 10 per cent calcium chloride solution. The performance to date of the many experimental paving projects built with air-entraining cements parallels the results obtained in the laboratory tests. The data contributed by the various agencies that have been working along these same lines, have aided greatly in the solution of the problem presented by the scaling of concrete pavements to which salts are applied during icy weather.

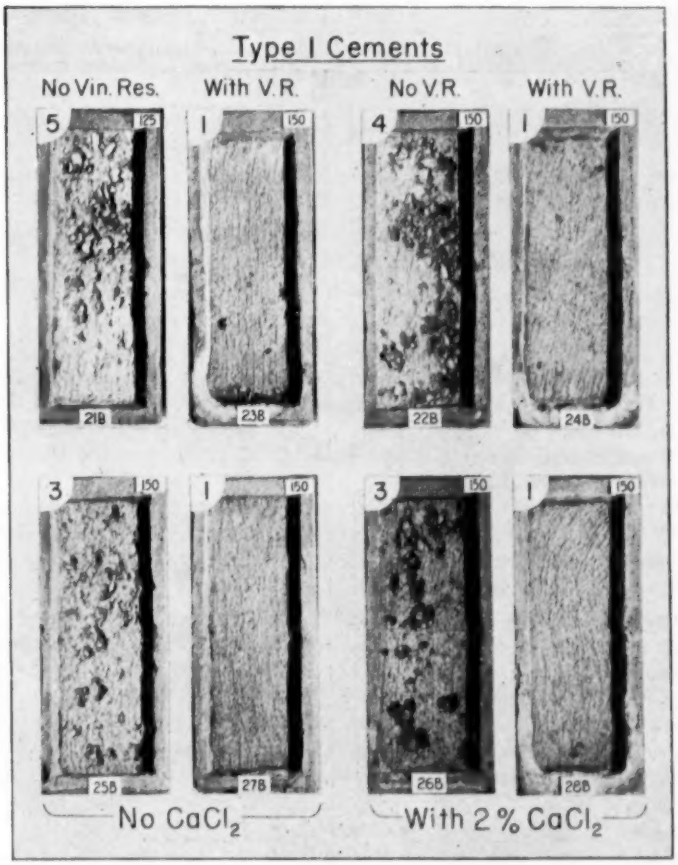

Fig. 12—Surfaces of typical concrete slabs after test for resistance to scaling—Series 310 (commercial Type I cements ground without and with .04 per cent Vinsol Resin)

Specimens in upper row were made with normal and air-entraining portland cements from Plant A. Those in lower row with normal and air-entraining portland cements from Plant B.

Aggregate: Elgin sand graded 0 to No. 4 sieve; crushed gravel from Dishneau, Michigan graded from No. 4 sieve to 1-in.

Mixes designed to have cement content of 6 sk. per cu. yd.; slump 3 to 4 in.

Slabs 1 day in molds, 6 days in moist room, 17 to 24 days in air and 4 days in water before testing for resistance to surface scaling.

Numerals at upper left corner of slabs are ratings of surface; those in upper right corner are cycles of freezing and thawing. For key to ratings of surface see notes of Fig. 4.

ACKNOWLEDGMENTS

Acknowledgment is made to the several state highway departments, and to the officials and members of the research staffs of these highway departments, who cooperated so generously in the construction of the various experimental road projects which provided much of the data for this report.

Acknowledgment is also made to Messrs. A. G. Timms, N. H. Withey, and A. S. Brock, formerly members of the staff of the Research Laboratory,

for their assistance in the conduct of the various tests reported herein, and to Mr. C. A. Menzel, Associate Engineer of the Research Laboratory for his assistance in the preparation of this report.

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Discussion of this paper should be submitted in triplicate to the ACI Secretary before September 1, 1944, for publication in the JOURNAL Supplement concluding Proceedings V. 40.

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JOURNAL
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7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN (Supplement) November 1944

Supplementary data and analysis for a paper by H. F. Gonnerman:

Tests of Concretes Containing Air-entraining Portland Cements or Air-entraining Materials Added to Batch at Mixer*

By H. F. GONNERMAN

In view of the interest shown in the effect which reductions in the percentage of sand in the mix may have on the air content and strength of concrete made with Vinsol resin added in a *NaOH*-water solution, data bearing on this question are presented in Table A. In this table are given results of tests with concrete mixes containing 5 and 6 sacks of cement per cu. yd. in which the percentage of sand was varied from 38 per cent or 40 per cent to 22 per cent by weight of the mixed aggregate. With each cement content two different slumps, 3 to 4-in. and 6 to 7-in., and two different amounts of Vinsol resin, .0075 per cent and .010 per cent by weight of the cement, were used.

Results of tests for compressive strength of 6 by 12-in. concrete cylinders at ages of 1, 7 and 28 days from Table A for concrete of 3-to 4-in. slump and with 6 sacks cement per cu. yd. are plotted in Fig. A. It is seen that upon reducing the percentage of sand from the initial value of 38 per cent, the strength of the concrete mixes without Vinsol resin at first increased slightly and then decreased. For the mixes containing Vinsol resin, there was a tendency for the strength to increase slightly with each decrease in the percentage of sand in the mix. The effect of sand reduction on strength was similar in character for both consistencies and for both cement contents. It will be noted that reduction in the percentage of sand was accompanied by a reduction in the water content of the concrete.

Reducing the sand percentage caused the air content of the concrete to decrease (see Fig. B). Reducing the sand percentage from 40 to 22 per cent decreased the air content as much as 1½ percentage points, the amount of the reduction depending upon the presence or absence of Vinsol resin in the mix. The rate of decrease in air content with

*ACI JOURNAL, June 1944; *Proceedings* V. 40, p. 477.

TABLE A—TESTS OF CONCRETE CONTAINING VINSOL RESIN ADDED IN SOLUTION—(Series 303)

(Effect of Varying Percentage of Sand)

Cement: Lot 16549, laboratory mixture of 4 brands.
Aggregate: Elgin sand and gravel graded as follows: 25%, 4⅜-in.; 50%, ⅜-¾-in.; 25%, ¾-1-in.
Water-cement ratio is the total water less the absorption of the aggregate at 10 minutes plus the water in the admixtures.
All specimens in molds 1 day then in moist room until tested.
The Vinsol resin-*NaOH* solution consisted of the following: 45 grams Vinsol resin, 7 grams *NaOH*, and enough water to make 2000 ml. of solution.
Each strength value is the average of 3 or 6 tests. Values of modulus of rupture are for center loading on 10-in. span.

Ref. No.	Mix by Weight	Sand, % by Wt.	Vinsol Resin, % by Weight	Fresh Concrete					Modulus of Rupture of 3x3x11¼-in. Concrete Prisms, lb. per sq. in.			Compressive Strength, lb. per sq. in.					
				W/C gal. per sk.	Cement Content, sk. per cu. yd.	Slump, in.	Unit Wt., lb./ cu. ft.	Air Content, %				3-in. Modified Cubes			6 by 12-in. Concrete Cylinders		
									1d.	7d.	28d.	1d.	7d.	28d.	1d.	7d.	28d.
NOMINAL SLUMP 3 TO 4-IN.																	
Cement Content—6 sacks per cu. yd.																	
233	1-2.20-3.59	38	0	4.95	5.97	3.2	151.8	1.6	265	770	975	1360	6040	7920	1170	4820*	6330
234	1-1.97-3.82	34	0	4.80	6.00	3.3	152.3	1.6	290	815	900	1540	6290	8260	1260	5150	6730
235	1-1.74-4.05	30	0	4.77	6.02	3.0	152.8	1.2	275	755	920	1450	6070	8120	1230	5230	6860
236	1-1.52-4.32	26	0	4.75	5.98	2.6	153.1	1.2	315	785	910	1670	6440	8220	1160	5080	6580
237	1-1.29-4.57	22	0	4.83	5.97	2.8	153.2	1.0	270	795	955	1510	6460	8150	1160	4920*	5950
201	1-2.13-3.47	38	.0075	4.80	6.01	3.3	148.7	3.7	265	740	870	1190	5220	7240	1130	4730	5960
202	1-1.92-3.73	34	.0075	4.79	5.99	3.3	149.2	3.4	265	775	925	1300	5320	7290	1210	4650	6290
203	1-1.71-3.99	30	.0075	4.73	5.98	3.0	149.8	3.2	300	800	930	1390	5390	7260	1220	4830	6360
204	1-1.50-4.25	26	.0075	4.69	5.98	3.3	150.8	2.8	295	805	865	1440	5790	7460	1320	4980	6500
205	1-1.28-4.52	22	.0075	4.66	5.97	2.2	151.6	2.3	280	735	830	1340	5770	7710	1270	5000	6540
206	1-2.12-3.45	38	.010	4.75	6.02	3.1	148.3	4.0	295	770	915	1300	5380	7220	1150	4670	6030
207	1-1.70-3.97	30	.010	4.75	5.98	3.6	148.9	3.7	275	800	835	1260	5330	7360	1180	4750	6240
208	1-1.26-4.46	22	.010	4.67	6.01	3.1	150.6	2.9	295	735	840	1430	5570	7660	1250	4830	6320
Cement Content—5 sacks per cu. yd.																	
238	1-2.83-4.24	40	0	5.72	5.01	2.7	151.2	1.9	205	645	840	970	4710	6860	830	4060	5860
239	1-2.54-4.53	36	0	5.72	5.02	3.5	151.7	1.6	210	695	890	1060	4870	7140	860	4200	5840
240	1-2.26-4.82	32	0	5.68	5.04	3.8	152.3	1.3	205	725	940	1050	4950	7240	830	4230	6050
241	1-2.00-5.15	28	0	5.63	5.01	3.9	152.7	1.2	200	750	900	1120	5230	7350	850	4180	6200
242	1-1.72-5.47	24	0	5.56	5.01	4.1	153.1	1.0	220	710	790	1110	4860	6870	810	3960	5690
209	1-2.76-4.14	40	.0075	5.67	5.00	4.0	147.8	4.0	200	625	785	850	4230	6280	760	3810	5560*
210	1-2.50-4.45	36	.0075	5.51	5.02	3.9	148.8	3.6	215	670	780	910	4430	6500	850	4080	5690
211	1-2.24-4.76	32	.0075	5.48	5.01	3.6	149.7	3.2	210	675	885	910	4550	6760	880	4080	5910
212	1-1.97-5.08	28	.0075	5.39	5.02	3.1	150.5	2.9	225	715	835	1110	4710	6880	910	4210	5860
213	1-1.70-5.40	24	.0075	5.33	5.01	3.4	151.2	2.6	225	700	895	1030	4600	6610	850	4150	5850
214	1-2.74-4.11	40	.010	5.46	5.02	3.0	147.3	4.6	210	665	840	890	4360	6130	740	3910	5400
215	1-2.22-4.73	32	.010	5.35	5.01	3.5	148.7	4.0	215	695	855	980	4540	6370	900	4180	5780
216	1-1.69-5.36	24	.010	5.29	5.00	2.8	150.0	3.3	225	685	820	980	4690	6570	880	4160	5760

NOMINAL SLUMP 6 TO 7-IN.

Cement Content—6 sacks per cu. yd.

243	1-2.18-3.55	38	0	5.32	5.96	6.4	151.0	1.5	250	700	875	1100	5160	7360	940	4150	6020
244	1-1.95-3.78	34	0	5.28	5.98	6.1	151.5	1.2	235	740	850	1080	5120	7410	900	4300	6200
245	1-1.72-4.02	30	0	5.26	5.99	6.6	151.9	1.0	245	710	880	1120	5140	7580	990	4390	6320*
246	1-1.50-4.25	26	0	5.22	5.99	6.3	152.0	1.0	210	780	865	1100	5330	7680	970	4500	6270
247	1-1.27-4.49	22	0	5.23	5.99	6.6	152.3	0.8	210	685	820	1130	5340	7580	925	4060	5670
217	1-2.11-3.44	38	.0075	5.21	6.00	6.3	148.0	3.4	230	710	830	960	4600	6700	910	4300	5940
218	1-1.90-3.70	34	.0075	5.17	5.98	6.5	148.5	3.2	230	700	870	990	4870	6900	940	4420*	5940
219	1-1.70-3.95	30	.0075	5.13	5.97	6.6	149.3	2.8	245	735	920	1020	5020	6680	950	4330	5910
220	1-1.47-4.20	26	.0075	5.09	5.97	6.2	149.6	2.7	245	695	875	1040	5030	6990	1000	4560	6100
221	1-1.25-4.45	22	.0075	5.05	5.97	6.1	150.2	2.4	240	690	860	1040	4970	6800	920	4280	5910
222	1-2.09-3.41	38	.010	5.06	6.01	6.4	146.8	4.4	240	610	830	940	4510	6310	950	4330	5820
223	1-1.68-3.92	30	.010	5.02	5.99	5.7	148.5	3.5	235	775	865	1030	5040	6900	970	4380	6050
224	1-1.25-4.42	22	.010	4.99	5.97	5.9	149.3	3.1	230	700	850	1140	5150	6900	1030	4420	6030

Cement Content—5 sacks per cu. yd.

248	1-2.82-4.24	40	0	6.15	4.96	6.0	150.3	1.8	195	690	855	810	4190	6430	670	3660	5540
249	1-2.54-4.52	36	0	6.12	4.98	6.2	150.9	1.5	190	690	815	820	4190	6520	660	3730	5440
250	1-2.26-4.81	32	0	6.08	5.00	6.5	151.6	1.2	165	660	825	800	4190	6260	700	3690	5570
251	1-1.99-5.13	28	0	6.06	5.00	7.4	152.4	0.7	170	710	865	790	4270	6440	660	3090	5290
252	1-1.71-5.42	24	0	5.96	5.00	6.9	152.5	0.8	180	635	755	900	4300	6330	600	3120	4830
225	1-2.74-4.11	40	.0075	6.07	4.97	6.5	146.7	4.1	160	600	785	630	3560	5480	600	3290	4880
226	1-2.48-4.42	36	.0075	6.00	4.99	6.6	147.9	3.5	170	640	810	670	3690	5830	660	3460	5320
227	1-2.22-4.73	32	.0075	5.92	4.98	6.5	148.7	3.1	165	610	805	720	3850	6100	650	3520	5390
228	1-1.96-5.04	28	.0075	5.85	4.99	6.5	149.4	2.8	180	635	855	750	4030	6170	700	3700	5340
229	1-1.69-5.36	24	.0075	5.78	4.99	6.5	150.4	2.4	175	630	785	830	4050	6150	690	3650	5230
230	1-2.70-4.05	40	.010	5.80	5.02	6.0	146.0	4.8	175	590	775	670	3670	5700	645	3430	4870
231	1-2.19-4.66	32	.010	5.73	5.02	6.2	147.8	3.9	165	690	800	740	3960	5870	695	3710	5360
232	1-1.67-5.28	24	.010	5.65	5.02	5.9	149.3	3.2	175	635	810	830	4200	6160	730	3440	5350

*Average of 2 tests.

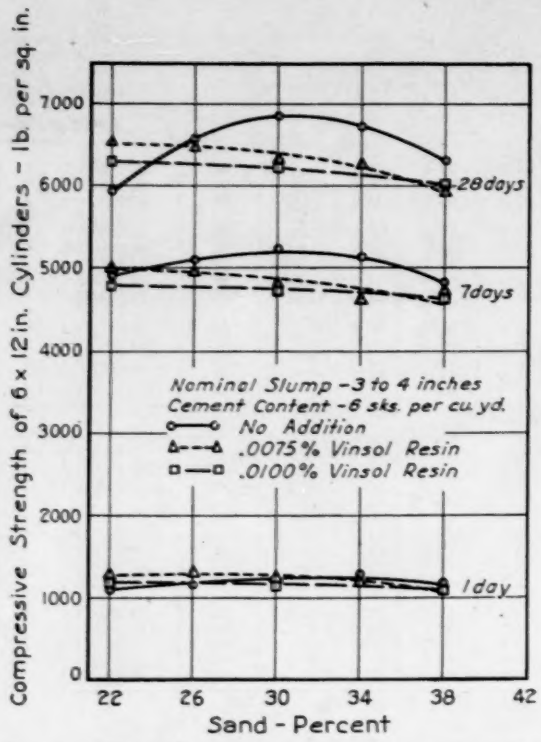

Fig. A—Effect of percentage of sand on compressive strength of concrete. Vinsol resin was added at mixer in solution with NaOH and water (1 part VR, 0.15 parts NaOH, 43 parts water by weight).

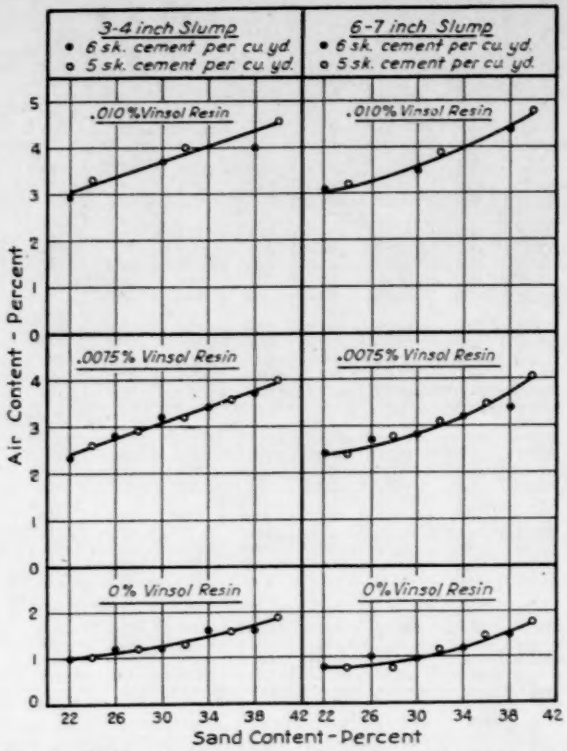

Fig. B—Effect of percentage of sand on air content of concrete. Vinsol resin was added at the mixer in solution with NaOH and water (1 part V. R., 0.15 parts NaOH, 43 parts water by weight.)

TABLE B

Ref. No.	Sand % by Wt. total aggregate	Vinsol Resin % by Wt. cement	W/C gal. per sack	Air Content %	Modulus of Rupture lb. per sq. in.			Compressive Strength lb. per sq. in.		
					1d.	7d.	28d.	1d.	7d.	28d.
Cement Content 6 sacks per cu. yd.; Slump 3 to 4 in.										
233	38	0	4.95	1.6	265(100)*	770(100)*	975(100)*	1170(100)*	4820(100)*	6330(100)*
201	38	.0075	4.80	3.7	265(100)	740(96)	870(89)	1130(97)	4730(98)	5960(94)
202	34	.0075	4.79	3.4	265(100)	775(101)	925(95)	1210(103)	4650(96)	6290(99)
203	30	.0075	4.73	3.2	300(113)	800(104)	930(95)	1220(104)	4830(100)	6360(100)
206	38	.010	4.75	4.0	295(111)	770(100)	915(94)	1150(98)	4670(97)	6030(95)
207	30	.010	4.75	3.7	275(104)	800(104)	835(86)	1180(101)	4750(99)	6240(99)
Cement Content 5 sacks per cu. yd.—Slump 2.7-4.0 in.										
238	40	0	5.72	1.9	205(100)	645(100)	840(100)	830(100)	4060(100)	5860(100)
209	40	.0075	5.67	4.0	200(98)	625(97)	785(94)	760(92)	3810(94)	5560(95)
210	36	.0075	5.51	3.6	215(105)	670(104)	780(93)	850(102)	4080(101)	5690(97)
211	32	.0075	5.48	3.2	210(102)	675(105)	885(105)	880(106)	4080(101)	5910(101)
214	40	.010	5.46	4.6	210(102)	665(103)	840(100)	740(89)	3910(96)	5400(92)
215	32	.010	5.35	4.0	215(105)	695(108)	855(102)	900(108)	4180(103)	5780(99)

*Values in parentheses are percentages of the strengths of the concrete without air-entraining admixture at a given age.

reduction in percentage of sand was slightly higher when Vinsol resin was used in the mix. This was true for both of the consistencies and cement contents used in these tests.

The results in Table B taken from Table A, show how a reduction in sand percentage can largely offset the reduction in flexural and compressive strength that occurs when the same percentage of sand is used with the air-entraining addition as with the concrete without addition:

It will be seen in Table B that when the percentage of sand is kept the same for the concrete with the Vinsol resin as it is for that without Vinsol resin, the strengths are, in general, lower. However, by reducing the percentage of sand when the air-entraining addition is used, the strengths can be maintained at approximately the same level as those for the concrete without the admixture. As stated in the original paper, reductions in percentage of sand when air-entraining cements or additions are used, should be governed by direct observations of the placeability of the concrete and the absence of honeycomb.

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Concretes Containing Air-entraining Agents

A SYMPOSIUM: Contributions by FRANK H. JACKSON, HENRY L. KENNEDY, HARMON S. MEISSNER, MYRON A. SWAYZE, DONALD R. MACPHERSON, GEORGE L. LINDSAY, HARRY F. THOMSON, ROBERT A. BURMEISTER, STANTON WALKER, RAYMOND E. DAVIS, GUY H. LARSON, JOSEPH H. CHUBB, R. T. SHERROD, J. F. BARBEE, F. V. REAGEL, reporting laboratory and field experiences with concretes containing air-entraining agents—and problems still to be solved.

An Introduction and Questions to which Answers are Sought

By FRANK H. JACKSON*
Member American Concrete Institute

HISTORICAL SUMMARY

Whenever the subject of air-entraining agents comes up for discussion —and that is often these days—I am reminded of an experience related to me by my friend Harold Allen, now with the Public Roads Administration, but one-time Materials Engineer for the Kansas Highway Department. As I recall, it was during the early 30's that Kansas, seeking to profit by an application of the water-cement ratio law, adopted a specification of this type for use in pavement construction. We all know that, under such a specification, any characteristic of a cement which will make it possible to increase yield and still stay within the requirements for water content and workability will be very attractive to the contractor. Furthermore, there is nothing wrong in utilizing such a characteristic provided, of course, the quality of the concrete does not suffer in any way.

It was, and still is, the practice of the Kansas Highway Department to make strength tests of concrete going into its pavements. On the basis of these tests certain values for strength are established as reasonable and any marked departure from the general trend is questioned. Along about 1934 it was noted that the strengths of concrete cores taken from pavements in which certain cements were being used were falling substantially below the level of expectancy. Mr. Allen became suspicious

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and soon found that these low strengths were invariably associated with low unit weights as measured by tests of the fresh concrete. A search for the cause revealed that the low weights were apparently due to the fact that small quantities of certain substances such as the stearates of lime and alumina, grease, coal and resin were being used as grinding aids in the manufacture of these cements and that these materials had the property of entraining air in the concrete. Of course, the beneficial effect of such materials, from the standpoint of increasing resistance to weathering, was not then realized. However, it was known that such cements did improve workability and on this account were proving very attractive, especially under a water-cement ratio specification. The increase in yield due to air-entrainment was also not overlooked.

The State was naturally concerned about the reduction in strength which resulted from the use of these air-entraining substances and steps were immediately taken to control their use through a requirement limiting the unit weight, utilizing for this purpose a simple liter weight test. This control, I understand, soon resulted in reducing the amounts of such materials to a point where the reduction in strength was not considered serious, thus solving the problem insofar as this particular situation was concerned.

I mention the foregoing incident merely to illustrate the change in our thinking on the subject of air-entrainment. A few years ago Kansas was using the liter weight test as a method of controlling a tendency which was then considered altogether undesirable. Now we are considering using this same liter weight test to insure that a certain amount (and not more than a certain amount) of air will be entrained in the concrete.

In introducing this subject I should like to trace briefly the development of the idea of introducing air into concrete for the purpose of improving durability. As we all know, the practice of applying sodium or calcium chloride, either mixed with sand and cinders or in the raw state, to icy pavements tends to induce surface scaling, particularly on new concrete. In an attempt to prevent this trouble the New York State Highway Department several years ago introduced the practice of blending natural with portland cement in its pavement concrete using a proportion of about 15 per cent natural to 85 per cent portland. Preliminary field experiments indicated that concrete containing the blended cement was considerably more resistant to salt action than comparable concrete made entirely of portland cement. In fact, the results were so outstanding that New York State, as well as most of the New England States, adopted the use of the blend as standard practice.

Speculation as to the reasons for this superior resistance developed two schools of thought. On the one hand it was argued that the improve-

ment was due to certain desirable characteristics inherent in the natural cement itself. On the other hand, the fact that, of the two natural cements used in New York State, the one which had produced the best results contained a small amount of beef tallow used as a grinding aid led many to wonder whether the improvement in scale resistance was not due merely to this fact or, in other words, whether the same benefits would not be derived by intergrinding the tallow with the portland cement itself. Incidentally this view was strengthened considerably by the discovery about this time that a certain portland cement having an exceptionally good service record in New York State contained a small quantity of oil or grease which had contaminated the cement as the result of leakage from the crusher bearings.

Recognizing the seriousness of the scaling problem, the Portland Cement Association about this time began an intensive study of air-entraining agents. The effect of introducing small quantities of materials such as tallow, fish oil stearate, resin, etc., either interground with the cement or introduced in liquid form at the mixer, was studied both in the laboratory and in the field.

Beginning in 1938 a number of experimental concrete pavements were constructed by several of the State Highway departments, certain cities and others, with the idea of demonstrating the effectiveness of this treatment under field conditions. The several test roads built by New York State, and the experimental street work carried out by the City of Minneapolis are examples. However, the field demonstration which has probably been most striking and certainly the best known is the one conducted by Moore at the Hudson plant of Universal-Atlas. These tests, with which you are all familiar, indicated definitely the possibilities of utilizing the air-entraining characteristic of certain materials to improve durability.

I think I am safe in saying that at this time our knowledge of the action of air-entraining agents is sufficient to warrant the conclusion that when properly used they do materially improve the resistance of pavements to what we term salt scaling. Furthermore, such laboratory data as I have seen indicate that entirely apart from salt action the resistance of concrete to repeated freezing and thawing is markedly improved. However, these data also clearly show that unless the amount of entrained air is controlled within rather narrow limits either the beneficial effects will be lost (as in the case of too little air) or the strength and possibly other properties of the concrete will be seriously affected (as in the case of too much air). Test data and experience both show that the quantity of air-entraining agent which will be required for optimum air content for any given combination of conditions will vary considerably, depending upon a number of factors, including kind of cement,

character and grading of aggregate, quantity of cement, type of mixing equipment, length of mixing time, etc. The effect of some of these variables will be called to your attention, by contributions to the discussion. I am convinced that all of them are of more practical importance than many of the all-out advocates of air entrainment seem willing to admit.

I suspect that the principal reason I was selected to open this discussion is the fact that, in some way or other, I have apparently placed myself in the position of being opposed to the use of air-entraining agents. As a matter of fact, I feel that what I have already said will convince you that I am not opposed in principle to this development. However, I am opposed to the idea which seems to be currently popular that, by simply adding a little Vinsol resin, tallow, Orvus, or what have you, to the concrete, we can build pavements which will last forever, and therefore all of our troubles are over.

QUESTIONS TO BE ANSWERED

Most good things have their limitations and to utilize the good we frequently have to take the bad. This is exactly the problem which confronts us in the practical use of air-entraining agents. Many concrete technicians have been so thoroughly sold on the subject of strength that they automatically view with alarm any condition which affects strength adversely. However, we have here a situation which may well justify the acceptance of some strength reduction for the sake of improved durability. In a sense, it becomes a problem of balancing one characteristic against the other; that is, securing a maximum of durability with a minimum loss in strength. Therein lies the importance of controlling closely the air content because it has been pretty conclusively proved that reduction in strength is a function of the amount of air entrained. Control of the air content of the concrete is the real problem. Therefore, granting the fundamental soundness of the principle of air entrainment, let us examine some of the practical problems that confront us in the application of this principle to the art of making concrete.

The first question concerns the method of adding the air-entraining agent. Should it be interground with the cement or should it be added as a separate ingredient at the time of mixing? There are advantages and disadvantages both ways. One obvious disadvantage of using a cement in which the air-entraining agent has been interground is the known fact that the amount of air which will be entrained in the concrete may vary considerably due to conditions surrounding the particular job. Therefore, merely to specify that the cement contain an air-entraining compound within certain limits as to amount will not insure that a

specified amount of air will be entrained in the concrete. Yet this is just what the present A. S. T. M. specification does. It is not adequate and attempts are being made to improve it by including a procedure under which acceptance of the cement is based on the amount of air entrained in a standard test mortar. Although this is a step in the right direction it is obviously not the complete answer. After all it is the amount of air in the concrete and not the amount entrained by a standard test mortar which is important. Why, I ask, in view of these uncertainties is it not more logical to add the air-entraining agent at the mixer, varying the quantity as needed on each job in order to secure the required amount with the materials at hand and under the practical working conditions which apply to that particular job?

My next question concerns the effect on strength—particularly flexural strength—a characteristic considered important by the pavement designer. Data now available indicate that, for the usual paving mixes, adequate protection insofar as resistance to frost action is concerned will be achieved with an air content ranging from 3 to 5 per cent. Within this range the crushing strength of the concrete may be reduced as much as 25 per cent and the flexural strength as much as 15 per cent as compared to the strength of the corresponding mix without the aerating agent. Granting that, insofar as paving mixes are concerned, the loss in crushing strength may be considered unimportant, the question arises as to the significance of a 15-per cent drop in flexural strength. Of course the strength may be brought back by redesigning the mix. Also, by taking advantage of the increased workability and yield brought about by aeration, the adjustment in many cases can be effected without unduly increasing cement content. However, experience has shown that, in certain cases it is impossible to secure the specified flexural strength without using cement factors as high as 7 sacks per cubic yard. There are some indications that, for these rich mixes, the increase in durability due to the use of an air-entraining agent will be proportionately less and, at the same time, the decrease in strength will be proportionately greater than would be true of the leaner mixes. Under these conditions a redesign to develop the required strength might result in undesirably high cement contents without any compensating advantage from the standpoint of durability.

For our third question let us leave paving mixes and consider structural concrete in general. Although officially the cement industry has so far confined itself to recommendations as to the use of air-entraining cements for pavements in areas where severe frost action prevails, I know that there is a strong feeling, not only within the industry itself but also among many users, that air-entraining agents should be used in all types of concrete exposed to the weather. This feeling is due

probably, not only to the fact that air-entrainment does increase resistance to frost action, but also to the increased workability, freedom from bleeding, water gain, etc., which appear to be associated with this type of concrete. These are all desirable qualities. However, in the case of structural concrete the question of bond strength with steel also demands attention. I have seen very little data on bond as affected by air-entrainment. However, I see no reason to doubt that about the same relationships exist as in the case of strength; in other words, that bond strength is reduced by air-entrainment and that the amount of reduction is proportional to the amount of air. I hope that we can have some discussion of this subject. Until authoritative data are presented to show that air entrainment introduces no problem in design, the question will remain. Highway bridge design engineers are traditionally conservative and until they can be shown that the advantages of using air-entraining agents outweigh their possible disadvantages they will not be used in bridge concrete.

A question which I know is in the minds of many here is the excessive air-entrainment which has been encountered on some transit mix operations. Whereas the actual number of instances has been small (to my knowledge, not more than 3 or 4) the effects have been startling, very serious reductions in strength having been observed. Most of the trouble seems to be the result of long-time mixing in closed drums, as much as 12 to 14 per cent air being entrained as compared to a norm of from 3 to 5 per cent. These instances are referred to here merely to emphasize again the importance of controlling air content within fairly close limits. Otherwise we have no control over strength whatever. So far as the application of the principle of air-entrainment to ready-mix concrete operations in general is concerned, I am sure that procedures can and will be developed which will prevent the recurrence of these troubles.

Another question having to do with air-entraining cements which I know is bothering the manufacturers is the problem of securing uniform distribution of the interground air-entraining agent. These materials are added to the clinker in such extremely small quantities (about 0.03 per cent by weight) that it is quite difficult to secure uniform distribution, especially when they are added in the dry form. Tests have shown that the bag to bag variations may be considerable. Consequently, since variations in the amount of interground materials will cause variations in air content and consequently in strength, an improvement in this regard is greatly to be desired.

It is impossible in a summary of this sort to discuss all of the problems which have arisen or which may arise as the result of attempts to apply the principle of air entrainment to the everyday operations of proportion-

ing, mixing and placing concrete. Many of these problems are constructional and cannot be solved in the laboratory. However, there is no reason to doubt that they will be solved as the result of actual experience in the field.

In conclusion, I would like to emphasize again what I consider the crux of the whole matter. In the preceding discussion it has been assumed that the improvements which are brought about by the use of the so-called air-entraining agents are due entirely to the fact that numerous minute and well distributed air voids have been introduced into the concrete, and that the sole function of the air-entraining agent is to produce these voids. This assumption may be questioned. In fact it has been questioned by some authorities who claim that the benefits derived are due primarily to the waterproofing qualities of such materials. I hope that there will be some discussion of this point However, if it is true that air voids are the important thing then obviously the optimum results for any job can best be secured by controlling the quantity of air which will be entrained in the concrete going into that particular job. How can this best be accomplished? That is the main question and I hope that the discussion which follows will furnish at least a partial answer.

The Function of Entrained Air in Portland Cement

By HENRY L. KENNEDY*
Member American Concrete Institute

My part in this discussion will be to point out a few of the indications resulting from continued investigations conducted in our laboratories in connection with the function of air entraining agents in portland cement concretes.

Reference is particularly to the investigation of two classes of air entraining agents (1) resinous materials and (2) a class of sulphonated materials including sulphated alcohols and sulphonated hydrocarbons.

These investigations substantiate the tentative conclusions in the paper, "The Function of Entrained Air in Concrete:"†

1. The enhanced durability of a concrete containing an air entraining agent is attributable to the entrained air rather than the agent.

2. The air entraining agents investigated had little or no beneficial effect on either the plasticity or the durability properties of neat cement paste even though some added air was entrained.

*Dewey & Almy Chemical Co., Cambridge, Mass.
†By Henry L. Kennedy; ACI JOURNAL, June 1943; *Proceedings* V. 39, p. 529.

3. The air entraining agents investigated had their major effect on the sand constituent of the concrete, varying in intensity with the size of the sand particles.

In this connection our investigation of the sand constituent showed that air entraining agents were not effective on size particles larger than retained on 14 mesh. Hence a study of the various particle sizes of sand finer than No. 14 in the presence of air-entraining agents, was conducted. The average relative amount of air entrained by the various sand fractions using identical mixing procedure, were as follows:

Size	Per cent Air
14-28	15-20
28-48	30-35
48-100	45-50
-100	0 - 1

It is obvious that radical changes in sand gradation could alter materially the total air entrained in a concrete. It is also obvious that air-entraining agents will show to greater advantage in lean mixes than in rich mixes.

It is interesting to note that whereas the water requirement for a given consistency for the sizes from 14-28 through 50-100 is progressively decreased, the water requirement for the -100 size is actually increased, being somewhat analogous to the action on neat cement.

When sand particles from 14-28 down to 50-100 in the presence of an air entraining agent are viewed under Leitz's Ultrapak microscope with oblique illumination, a ring of ball-bearing-like air bubbles is noted clinging to each sand particle, forming a perfect means of aggregate lubrication. As the sand particles become smaller the ball bearings become smaller but more numerous. But when the particles are less than 100 mesh, no ball bearings are discernible; rather the particles seem to be compacted.

Plasticity, workability and/or consistency will be increased directly in proportion to the amount of air entrained by the fine aggregate.

Strengths will be proportionately reduced with increased air content until it seems reasonable that a critical point may be reached where lack of sufficient strength may defeat the beneficial effect of entrained air. Hence excessive plasticity, because of excessive air, may be dangerous.

Perhaps the following investigations carried on at our laboratory may help to illustrate this danger.

A half-bag drum-type concrete mixer was used to make an *apparent* concrete. The mix was a 1:2.5:3.5 with .03 per cent of an air entraining agent based on the cement factor. But the cement itself was eliminated from the mix. The water added was just sufficient to give a damp,

harsh consistency to the sand; in other words a consistency that required some pressure of the hand to compact the sand with no free water apparent. The mixer, which operates at 18 rpm., was started and the air entraining agent added in solution.

For the first few minutes nothing could be observed but a cascading of the segregated gravel and the damp sand. The appearance of the mix was harsh, even crumbly. But during the next two minutes, the apparent concrete developed a flowing consistency. The mix was really an excellent looking concrete showing no segregation of the larger aggregate as it was discharged from the mix and during subsequent handling. It showed a slump of six inches. The measured air content was 10 per cent. The larger aggregate particles were completely coated with a paste of air and sand. (In subsequent tests a teaspoonful or more of carbon black was added to the sand to simulate a concrete using dark cement). Subsequently the air was evacuated and the mass became harsh. The sand and segregated aggregates had no paste coating.

A general contractor, now working at our plant, who had no knowledge of the ingredients in the mix, was called to the laboratory for an opinion of the mix based on appearance. "You can pour that kind of concrete for me any day," was his reaction. Remember not an ounce of portland cement was used in the mix.

Because excessive air will produce this remarkable plasticity even in the total absence of portland cement, unwarranted reduction in cement content may inadvertently result to the detriment of the finished concrete.

Air-entraining agents are unquestionably here to stay. However, the air content must be controlled because, (1) insufficient added air will not produce the enhanced durability attributable to entrained air; (2) Too much air, hence, plasticity may be dangerous.

Laboratory Freezing and Thawing Tests on Concretes Containing Various Air-entraining Agents

By HARMON S. MEISSNER*
Member American Concrete Institute

Investigators have for some time observed that various additive materials will increase the workability and slump of concrete, but they will also generally decrease its unit weight. Such decrease in unit weight has usually been accompanied by reduced compressive strength and for this reason, in the past, such additions have been considered deleterious and their use has not been encouraged. Apathy toward

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these additions has persisted even though strengths, approximating those obtained without the admixtures, can be secured by taking advantage of the increased slump and workability which they afford and accordingly reducing the water-cement ratio. The decreased density of the concrete was soon, and correctly, ascribed to an increase in occluded air and such additives received the description of "foaming agents" or "air-entraining agents." Also, the added plasticity which they provided the freshly mixed concrete was immediately associated with their capacity to entrain air.

It was not until some desirable quality was discovered in the concrete, due to the hitherto undesired air content, that these admixtures received any approbation. After tests and experience had demonstrated that pavement concrete containing more than the usual one per cent (or thereabout) of occluded air had superior resistance to scaling when treated with calcium chloride to remove ice, there arose a general realization that some strength might be sacrified in the interest of this quality, should it be of greater importance to the intended service. This view finally found official expression in A. S. T. M. tentative standard "C175-42T, Treated Portland Cement for Concrete Pavements"; although in this specification the additive is incorporated in the cement and no mention is made of the fact that the cement entrains air in the concrete.

Two major effects of air-entraining agents on concrete have been recognized; (1) their power to incorporate air in the mix, and (2) their effect upon hydration of the cement. Their virtues are dependent entirely on the first of these which, however, also reflects negatively on the strength of the concrete, while the second may or may not be operative. The effect of most air-entraining agents on the hydration of cement is deleterious and, when combined with a reduced concrete density, they produce strengths much lower than can be compensated by any accompanying reduction in water-cement ratio. If, however, the additive does not interfere with the proper hydration of the cement, it is possible to secure the desirable attributes of entrained air without the sacrifice of other qualities, and the better air-entraining agents should be judged in this light.

Tables 1, 2, and 3, and Fig. 1, 2, and 3 present the results of several series of tests on air-entraining agents, made in the laboratories of the Bureau of Reclamation. The data in each table are directly comparable with those for the control group made without an additive. The specimens were all 3-in. diameter by 6-in. concrete cylinders containing ¾-in. maximum aggregate, mixed to the same slump consistency, and cured at 70 F. in a fog room for 14 days, followed by drying at 70 F. and 50 per cent relative humidity prior to subjecting to freezing and thawing. Strengths shown were obtained at the beginning of the freez-

ing and thawing test, which was performed by placing the specimens in close-fitting rubber containers filled with water and alternately immersing these in brine at 5 F. and water at 70 F. The periods of freezing and thawing were each 90 minutes, during which time the centers of the specimens reached 15 F. and returned to approximately 70 F. in an equal interval.

One will observe from Table 1 that a reduction in compressive strength has accompanied the use of all agents listed, and that no improvement in durability was secured with calcium stearate or stearic acid. These two additives did not entrain air, nor did they provide any workability to the mix as judged by the higher water-cement ratios used with them. On the other hand tallow, rosin, and Vinsol resin all entrained air in the mix and all added tremendously to freezing and thawing resistance. It is indicated in the case of Vinsol resin that such resistance is also in proportion to the amount of air entrained.

Looking at the data in Table 2 it is at once obvious that the fatty alcohol sulfate has been used in quantities far greater than would be practicable. However, the amount of occluded air is proportional to the amount of agent used, as is also, except in one case, the reduction in water-cement ratio. In spite of the large decrease in strength, every one of the groups in this table has been benefited with respect to its durability by an increase in air content.

TABLE 1

Air-entraining agent	Per cent agent by wt. of cement	Mix—42 per cent sand	W/C by wt.	Per cent air	Comp. strength psi	Cycles of F. & T. to:	
						0.1% expansion	25% loss in wt.
None	None	1:5.5	0.54	2.1	5,910	320	410
Stearic acid	0.10	1:6.0	0.55	2.7	5,010	360	370
	0.50	1:5.5	0.56	2.9	4,810	280	275
	1.00	1:6.0	0.66	3.4	3,140	130	120
Calcium stearate	0.05	1:6.1	0.56	2.8	4,640	400	480
	0.10	1:5.5	0.56	2.)	5,520	270	360
	0.50	1:5.5	0.60	2.4	4,300	92	140
Tallow	0.01	1:5.5	0.54	6.3	4,990	800+	800+
	0.05	1:5.5	0.54	10.4	3,760	800+	800+
	0.10	1:5.5	0.53	8.3	3,590	750	750
Rosin	0.01	1:5.9	0.52	12.8	3,800	1,000+	1,000+
	0.03	1:5.5	0.51	15.2	3,140	1,000+	1,000+
	0.05	1:5.4	0.50	13.3	3,320	1,000+	1,000+
Vinsol resin	0.01	1:5.9	0.53	3.7	5,030	850	930
	0.03	1:5.5	0.53	6.6	3,520	1,000+	1,000+
	0.05	1:5.4	0.53	10.0	2,870	1,000+	1,000+

TABLE 2

Mix 1:2.31:3.19 by weight

Air-entraining agent	Per cent agent by wt. of cement	W/C by wt.	Per cent air	Comp. strength psi	Cycles of F. & T. to: 0.1% expansion	Cycles of F. & T. to: 25% loss in wt.
None	None	0.54	2.3	6,430	105	190
Fatty alcohol sulfate	0.01	0.56	5.7	2,890	1,000+	1,000+
Fatty alcohol sulfate	0.03	0.53	9.4	3,390	800	800
Fatty alcohol sulfate	0.05	0.49	12.4	2,810	900	900
Fatty alcohol sulfate	0.1	0.54	16.0	1,910	640	640
Fatty alcohol sulfate	0.5	0.51	26.7	1,100	130	130
Aluminum powder	0.02	0.54	—	2,930	1,000+	1,000+
Aluminum powder	0.01	0.54	—	3,970	1,000+	1,000+
Rubber emulsion	1.80	0.56	13.3	3,190	700	730
Sulfonated castor oil	0.015	0.50	11.1	4,510	1,000+	1,000+
Fatty alcohol sulfate	0.015	0.50	5.8	4,980	1,000+	1,000+
Vinsol resin	0.030	0.48	11.6	3,510	1,000+	1,000+

TABLE 3

Mix 1:2.41:2.89 by weight

Air-entraining agent	Per cent agent by wt. of cement	W/C by wt.	Per cent air	Comp. strength psi	Cycles of F. & T. to: 0.3% expansion	Cycles of F. & T. to: 25% loss in wt.
None	None	0.55	2.0	5,490	92	100
P	1.00	0.50	2.8	6,080	105	113
T	0.05	0.52	2.6	4,240	53	118
A	0.05	0.53	2.9	5,720	150	150
N	0.015	0.51	3.9	4,960	400+	400+
V	0.030	0.52	5.0	4,530	400+	400+
L	0.033	0.53	3.1	5,000	300+	300+
G	0.015	0.55	1.8	5,260	116	140
G	0.035	0.53	2.8	5,200	300+	300+
S	0.16	0.52	2.0	5,250	198	225
S	0.20	0.52	2.4	5,380	243	250
S	0.28	0.50	3.5	5,200	300+	300+

Table 3 shows the results of tests with miscellaneous additives, not all of which have been used in amounts large enough to entrain sufficient air to make their affect on durability very pronounced. Yet there is evidence in this series that increased resistance to freezing and thawing is achieved when an appreciable amount of air is put into the concrete. In the case of several agents these results are at no expense to compressive strength.

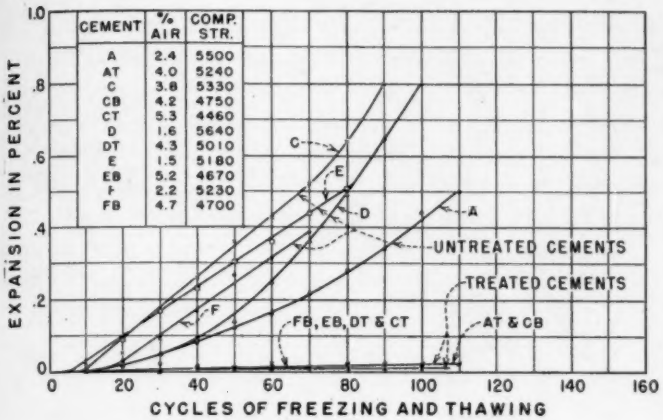
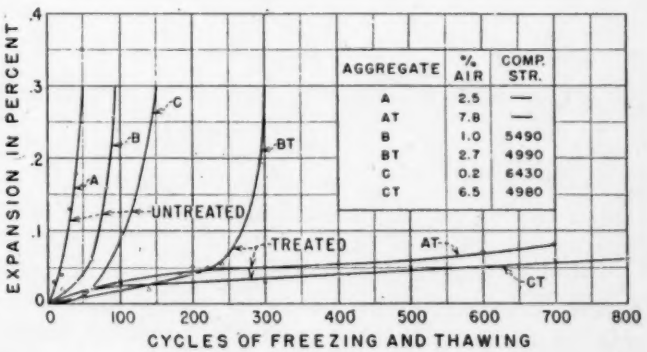


Fig. 1—Air-entraining agents make concrete more resistant to freezing and thawing

Fig. 1 portrays the results on concretes made with the same aggregate using five cements with and without Vinsol resin treatment. The letter T on the chart indicates that the clinker in question was ground with 0.3 per cent Vinsol resin to a fineness equivalent to that of its untreated counterpart. The letter B means that neutralized Vinsol resin was added to the concrete mix in this same amount. The uniform benefit to durability, coincident with entrained air, attributable to this agent is evident, although a slight decrease in compressive strength may also be noted.

Fig. 2—Increased durability is obtained when an air-entraining agent is added to concrete



In Fig. 2 are depicted tests with one cement, ground to equal fineness with and without Vinsol resin, incorporated into concrete using three different aggregates. The letter T again identifies the treated cement. Here we note again the improved durability secured with the air-entraining agent; but it may be observed that the results are less pronounced with one aggregate and that in this case the amount of entrained air was also not as great.

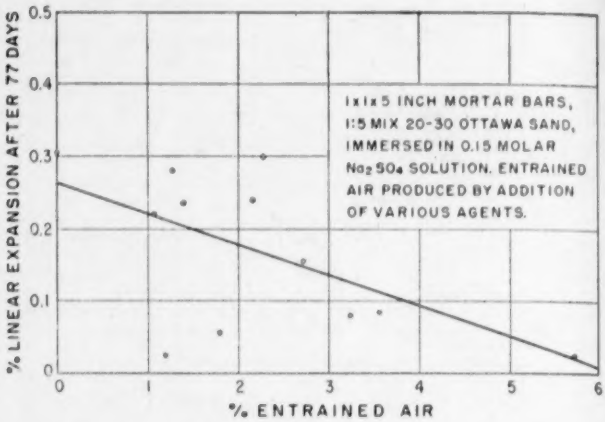


Fig. 3—Entrained air increases the resistance of mortar to sulfate attack

In addition to the foregoing data, tests have been made to determine the effect of air-entraining agents on the resistance of cements to the attack of alkali-sulfate waters. Various agents were incorporated in the manufacture of lean mortar expansion bars subjected to immersion in sodium-sulfate solution, and in Fig. 3 their expansions after 77 days are plotted against the amount of air calculated to be in the mortar. The cement in this instance is a normal cement, calculated to contain 10.7 per cent tricalcium-aluminate, and it may be concluded that entrained air has in general improved its resistance to the test. However, similar tests on cements of lower tricalcium-aluminate content have indicated no improvement from air-entrainment.

Air Entrainment Calls for Changes in Mix Design and Mixing Practice

By MYRON A. SWAYZE*
Member American Concrete Institute

Our research laboratory has been working with air-entraining cements for the past ten years. Our data, which include many hundreds of tests, have been published in brief, so without restatement I wish to look into the future a bit.

Normal cement concrete frequently has two deficiencies on which we can all probably agree: it needs more workability in ordinary mixes, and in severe winter exposures it needs greater durability. I think from all the data which have been presented that it now can be taken for granted that air-entraining cement provides the cure for these two faults.

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However, if we examine the performance of these new products, we find considerable variation from one brand to another. Some cements have developed excessive amounts of air in concrete even when the resin content is close to the minimum, while a few produce too little air with the resin at the maximum. To remedy this condition, a change in the A. S. T. M. specifications is now under way which will put air entraining power on a performance basis, rather than merely limiting the range of allowable resin. This change should iron out most of the variation in air content now found between brands.

Even after this change is made, it must be remembered that this specification is written for concrete pavements only, which means fairly rich mixes and relatively low slumps. When the air-entraining cements are employed in leaner mixes, or for structural work where concrete of higher slump is necessary, the user is going to find greater amounts of air entrained than is encountered in pavement work.

For any use, whether it is in highways, reinforced concrete, or what-not, the user should by all means redesign his mixes accordingly. For those using the Abrams Maximum Fineness Modulus Table for proportioning sand and coarse aggregate, I would suggest that this table no longer holds for air-entraining cements, since the air acts as a substitute for sand in producing workable mixes. Where mixes have been worked out for the optimum sand content with normal cements, approximately 1 per cent of sand should be cut out for each 1 per cent of air introduced by the air entraining cement. Decreasing the sand content in this manner will decrease the water-cement ratio and materially increase concrete strengths over what would be obtained otherwise.

Concerning ready-mixed concrete, I understand some trouble has occasionally been encountered with excessive air in the batches. While some of this may have come from too great an air-entraining power in the cement, excess sand in the batch and high slump mixes, part of the excess must be charged purely to overmixing of this type of concrete. The proposed changes in the air-entraining cement specification will help greatly in controlling the maximum amount of air for ordinary concrete. However, these changes must be supplemented by others in the present methods on operation of transit mixers if air in ready-mixed concrete is to be held within a reasonable range.

In general, most specifications for transit mixing require slow speed rotation of the drum after a brief, rapid mixing. With normal cements, this provision is an essential part of the operation, as otherwise segregation would often occur and the mass "harden" in the drum in transit, due purely to mechanical interlock of aggregates. With the air-entraining cements, concrete shows very little tendency toward segregation, and the need for slow speed agitation is therefore greatly reduced if not

eliminated. With central mixing, the batches can usually be transported in ordinary dump trucks without difficulty in discharging at the job. Therefore, I would urge a liberal interpretation of transit mixing specifications by both operators and purchasers of this type of concrete, until such time as revisions can be made in the currently specified methods.

Finally, let me emphasize strongly that the mere presence of air-entraining agents in concrete, whether they are interground with the cement or added at the mixer, is no "cure-all." Personally I am much in favor of a reasonable amount of air-entrainment in concrete, and foresee a bright future for this sort of portland cement. However, merely because we use an air-entraining agent with the cement, we still cannot use unsound or contaminated aggregates, forget proper proportioning of mixes, nor "repeal" the law of water-cement ratio. We still need a lot of both logical thinking and work on such homely subjects as finishing of concrete surfaces and methods of curing. After all, surface scaling is at least partially a function of the finishing method. We have a wealth of information on these subjects in every hardened concrete surface, if we would but read the signs. Air-entraining agents will improve the workability and durability of concrete, but their presence in a concrete mix must never be considered as a substitute for good practice in mix design, or in the placement, finishing and curing of concrete.

Methods of Entraining Air in Concrete

By DONALD R. MACPHERSON*
Member American Concrete Institute

One of the most important developments of recent years is the use of air-entrainment to improve durability in paving concrete. It promises to effect great economies in highway maintenance. Since many data have been accumulated on the durability phase of air-entrainment, this contribution is confined to the less familiar subject of various methods of entraining air, and will include data to illustrate the advantages and limitations of materials currently employed. Since the information on air-entrainment is limited and that which is known has not been widely publicized, it is not surprising that the field engineer on occasion has had difficulty in securing the desired results.

The two principal methods employed to increase the air-content of pavement concrete are (1) the use of treated cements which have had fatty or resinous materials interground with the clinker during manu-

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facture and (2) the use of untreated cements to which separate air-entraining materials are added when the concrete is mixed. The first of these methods has the advantage of convenience because it saves time and labor at the mixer. However, the method has decided limitations because it does not afford the field engineer direct and accurate means of obtaining the desired amount of air-entrainment in his concrete which he otherwise could have if the air-entraining agent were added separately. The field engineer is entitled to the full control of the air-entraining agent so that the air content of his concrete can be kept within narrow limits and thereby avoid great losses in strength. Actual field experience reported by J. W. Kushing†, showed that close control and uniform results were easier to obtain and maintain when a foaming agent was added separately.

A study of the intrinsic properties of the materials that have been used both in the field and in the laboratory to entrain air in concrete, will reveal marked differences that are worthy of consideration. These materials can be separated into two distinctly different classes of substances, namely: the water-insoluble, fatty or resinous materials and the water-soluble foaming or wetting agents. Since these two classes of substances have quite different chemical properties and entrain air in concrete by different mechanisms, it could be expected that they would perform differently. Fatty or resinous materials, which are usually interground, should not be classified as foaming agents because they do not possess the property of lowering the surface tension of water, which is characteristic of foaming agents. Therefore, if fatty or resinous materials are to entrain air they first must be converted into soaps through saponification with the alkali and alkaline-earth metals present in the liquid phase of a concrete or mortar mix. Obviously, for a given quantity of saponifiable material interground, cement composition can be expected to influence the completeness of the saponification reactions and thereby affect the degree of air-entrainment. In some instances this situation makes for wide variations between different cements in the amount of air entrained, which in turn may adversely affect the flexural and compressive strengths of the resultant concrete. For example, the data given in Table 1 illustrate this point with respect to extreme variations in air-content.

The plastic mixes used to obtain the data shown here and in the tables to follow, were all machine mixed with mixing time, sand-total aggregates ratio, cement factor, and consistency constant unless otherwise mentioned. Pea-gravel was used as coarse aggregate in the mixes reported which with the same quantity of saponifiable material, the two laboratory treated cements give entirely different amounts of air-entrain-

†"General Observations on Concrete Scaling," J. W. Kushing, *Roads and Streets*, Dec. 1941; V. 84, p. 23

ment (last column of Table 1). Treated cement A gives very little entrained air and yet the quantity of additive is close to specification limit (second line in Table 1). In Table 2 a similar situation is shown but in this case ¾-in. stone was used in the plastic mixes.

TABLE 1

Cement	Addition Per Cent by Weight	Unit Weight P. C. F.	Approximate Increase in Air—Per Cent
A	None	144.2	0.0
A	.04 Saponifiable Material	143.1	0.8
B	None	145.0	0.0
B	.04 Saponifiable Material	133.9	8.7

The cement factors in the laboratory treated cement mixes were lowered by the air-entrainment. Here again it is shown that two clinkers from different sources, interground with the same amount of saponifiable material, give markedly different amounts of additional entrained air. (last column of Table 2).

TABLE 2

Cement	Addition Per Cent by Weight	Unit Weight P. C. F.	Approximate Increase in Air—Per Cent
C	None	147.6	0.0
C	.03 Saponifiable Material	143.8	3.1
D	None	148.2	0.0
D	.03 Saponifiable Material	139.6	6.2

Existing specifications allow the cement manufacturer to vary the quantity of saponifiable material interground with the cement clinker to suit the inherent chemical properties of each cement with respect to its air-entraining qualities. On the basis of field experience it is questionable whether the percentage limits established will allow all treated cements to perform in a similar manner with reasonably close control of entrained air. In adopting intergrinding as the method of obtaining air-entrainment in concrete, it would be desirable to use a water-soluble foaming or wetting agent, which for a fixed percentage addition in all cements, would give reasonably constant amounts of air-entrainment under a given set of conditions of control of field concrete. This procedure however, still denies the field engineer the separate control of each ingredient in his concrete mix which he should have to obtain the desired amount of air-entrainment under different job conditions.

The data given in Table 3 show the performance of two commercially treated cements in ¾-in. stone mixes at two different cement factors.

It will be noted that the two treated cements behave quite differently with respect to amounts of air entrained (last column). Insufficient air is entrained in one of the rich mixes with one cement and in one of the lean mixes with the other cement (first and last lines, Table 3).

TABLE 3

Cement	Addition—Per Cent by Weight	C. F. S. C. Y.	Total Measured Air—Per Cent
A	.04 Saponifiable Material	7.1	1.6
B	.025 Saponifiable Material	7.2	3.3
A	.04 Saponifiable Material	4.6	3.6
B	.025 Saponifiable Material	4.6	2.0

A great variety of water-soluble wetting agents have been used in the laboratory for the purpose of entraining air in concrete. Those which function in an alkaline medium without chemical alteration and without detrimental effect on the hydration reactions of portland cement are the most suitable. To be effective, these materials should give large reductions in surface tension for very dilute water solutions. Sodium lauryl sulfate, one of the better known of these materials which has been used in the field, gives a reasonably uniform air-content with different cements in a mix under controlled conditions. This is illustrated in Table 4 where data are shown for pea-gravel mixes.

TABLE 4

Cement	Addition Per Cent by Weight	Unit Weight P. C. F.	Approximate Increase in Air—Per Cent
A	None	144.2	0.0
A	.04 Saponifiable Material	143.1	0.8
A	.01 Na-Lauryl Sulfate	138.2	4.7
B	None	145.0	0.0
B	.04 Saponifiable Material	133.9	8.7
B	.01 Na-Lauryl Sulfate	138.9	5.0

Here it is shown that the two cements A and B used previously with the same amount of interground saponifiable material which gave radically different amounts of air-entrainment (second and fifth lines in Table 4) now give fairly uniform air-contents under the same conditions of test where the same amount of a separately added water-soluble foaming agent is used. (third and sixth lines, Table 4). It should be mentioned at this time that the amount of air-entrainment in pea-gravel

mixes is usually higher than it would be in paving mixes of comparable consistency where there is a much lower ratio of sand to total aggregates.

The data in Table 5 illustrate that the task of obtaining reasonably uniform amounts of air-entrainment, with all cements, can be obtained with a separate air-entraining agent.

TABLE 5

Cement	Type of Cement	Addition Per Cent by Weight	Unit Weight P. C. F.	Approximate Increase in Air—Per Cent
All Cements	—	None	144.2—145.2	0.0
A	I	.027 HP-7	137.0	6.6
B	I	.027 "	137.0	6.8
B	III	.027 "	137.3	6.6
E	IV	.027 "	137.2	6.3
F	I	.027 "	136.8	7.4
G	I	.027 "	137.0	6.8
H	II	.027 "	136.8	7.1
I	II	.027 "	137.1	6.7
			Average	6.8

The air-entraining agent in this case is a homogeneous mixture in powder form of the foaming or wetting agent sodium lauryl sulfate, the cement dispersing agent calcium lignin sulfonate and a pozzolan. Since the cement dispersing agent allows substantial lowering of the water-cement ratio, an increase in strength can be obtained with a given cement factor. This is accomplished with about 3 per cent additional air in paving mixes. On the other hand, air-entraining agents which function only to entrain air, will lower strengths.

The data shown in Table 5 were obtained from pea-gravel mixes using 8 different cements, representing 4 different types. Here it is shown that the increase in air-content with a given addition of the agent is fairly uniform (last column). The minimum increase in air is 6.3 per cent and the maximum increase is 7.4 per cent. These data are typical with respect to uniformity of air-entrainment with a much larger number of cements which have been tried. However, it will be noted that some variation in air-content does exist under very carefully controlled laboratory conditions and since the additive has been introduced separately it is relatively easy to alter the amount slightly so that the additional entrained air can be held constant for all mixes shown. By this procedure only, can the risk of wide variation and substantial strength loss be minimized.

In conclusion, it may be well to mention again that for a given cement factor, lower strengths cannot be avoided in air-entrained concrete if the agents used are effective and function only to entrain air. Opinion

is divided on the question of whether any loss in flexural and compressive strengths in highway concrete containing air-entraining agents should be accepted in order to obtain better durability. If the lower strengths secured in the air-entrained concrete are adequate, then it would appear that over-design has been the common practice. Those who, when a given strength design and cement factor are established, are not willing to accept lower strengths in exchange for the improved durability benefits of entrained air, must use an air-entraining agent which will protect all properties of their concrete as well as to entrain air.

Manufacture and Use of Air-entraining Portland Cement

By GEORGE L. LINDSAY*
Member American Concrete Institute

The Universal Atlas Cement Co., as well as technical departments of State Highway Departments, the Portland Cement Association, the Federal Government and other agencies, searched for a long time for effective measures to accomplish reduction or elimination of surface scaling in concrete pavements.

Our earlier studies covered the scale resistance of regular and special cements available at that time. Little or no advantage was found in one type of portland cement over another type.

In these studies our scaling tests were made on 12 by 12 by 3-in. concrete slabs, having a mortar dike 1 in. high around the surface of each slab. Concrete had a cement factor of 6 sacks per cu. yd. with sufficient water to give a slump of 2 to 3 inches. Surface was given a broomed finish similar to that used in finishing highway pavement slabs. Slabs were cured one day in molds under moist burlap, 9 days in fog room, and 4 days in laboratory air, after which they were placed out-of-doors.

LABORATORY RESEARCH OF SCALING

Water to a depth of ¼ in. was placed on the surface of each slab, allowed to freeze over-night (weather permitting) and the next morning the ice was melted by applying raw flake calcium chloride—2.2 lb. per sq. yard. When the ice was completely melted, the thaw water was poured off the surface and the slab was brushed with a stiff wire brush and flushed with clear water. This was considered one cycle.

To measure the amount of scaling, a wire grid consisting of 25 equal squares was placed on the surface of the specimen. Each square in the grid was visually divided into quarters and the amount of scaling in

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each quarter estimated. If scaling appeared in only one quarter of a square of the grid, the figure "1" was placed on a work sheet which was ruled off in squares similar to those of the grid. If scaling was present in half of a given square the figure "2" was used; if in three-quarters of the square the figure "3"; and if all of the area under a given square was scaled the figure "4" was used. The sum of the figures in each square was considered the percentage scaling of the slab surface.

Following our failure to find outstanding scale-resistant properties in concrete of different types of cement we turned to what we then called "plasticizing agents" to improve the workability of concrete and thereby reduce segregation and bleeding which we felt were major factors in scaling. A number of plasticizing agents were experimented with and a marked improvement was found with certain of these materials interground with portland-cement clinker. Concretes made with materials showing the greatest scale resistance were all distinguished by a lower weight per cu. ft. and an increased slump. Two supposedly similar materials would act differently; for example, pure calcium stearate produced little or no improvement in scale resistance and no loss in weight per cu. ft. of concrete while an impure calcium stearate produced excellent scale resistance and a lower weight per cu. ft. of concrete. The impure stearate was investigated and found to be fish-oil calcium stearate, the improvement coming from the fish-oil rather than from the calcium stearate. Many test data accumulated during these investigations pointed in an unusually consistent and conclusive way that here was the solution—air-entraining cements.

ROAD TO TEST AIR-ENTRAINING MATERIALS

Being thoroughly familiar with the vagaries of laboratory data when submitted to full-scale field experiment, we decided to have an experimental road built at our Hudson, N. Y., plant. It was constructed during the late fall of 1938 under standard New York State Highway specifications by an experienced contractor, using the usual highway equipment. The road, serving as the main entrance to the plant, is 540 ft. long and 18 ft. wide, with an 8-7-8-in. cross-section. It is divided into 20-ft. lengths separated by dummy joints, each length containing concrete of a given type. Duplicate lengths, not contiguous, were constructed for each type of cement and sand used.

Two kinds of sand were used. The first half of the road was constructed with a sand having a good service record and showing a loss of about 4 per cent in the sodium sulfate test for durability, while the second half was built with a sand having a poor service record and showing a loss of 20 per cent in the sodium sulfate test. In addition, several slabs were laid of very wet consistency, with cement and sand as the variables.

Cements used in the construction of the pavement were:

Regular portland
Coarse-ground portland
Portland plus natural, mixed 6:1 by wt. on the job
Portland with an addition of fish-oil stearate ground in at the cement mill
Portland with an addition of Vinsol resin ground in at the cement mill

All of the portland cements were from a single mill.

DATA FROM EXPERIMENTAL ROAD

During the first two winters, 1938-39 and 1939-40, tests using calcium chloride for ice removal were made on a 6-ft.-square section of each slab of the road. Dikes were built around the sections and water added. When freezing occurred, the ice was melted with 2 lb. of flake calcium chloride per square yard of surface. A total of 61 cycles of freezing and thawing was obtained in this way during the two winters.

The slabs constructed of regular cement, of both finenesses, and inferior sand were completely scaled after the first 10 to 15 cycles of the treatment. With the good sand, both finenesses gave a better performance. The portland-natural blend gave a better performance than the regular cements, especially during the first winter, when no scaling occurred with the good sand, against 15 to 23 per cent scaling with the inferior sand. However, scaling of the blend progressed rapidly during the second winter, reaching rather high percentages especially with the inferior sand.

In the portland-cement concrete containing fish-oil stearate or Vinsol resin, not a trace of scaling developed during the first winter with either inferior or good sand, and only a relatively small amount the second winter.

A complete report on the Hudson experimental road was prepared by O. L. Moore.*

By the spring of 1939, several of the agencies investigating the scaling of concrete pavements were exchanging test data and it was apparent that small quantities of air-entraining materials interground with portland-cement clinker held definite promise of improving the resistance of portland-cement concrete to scaling caused by freezing and thawing and applications of common salt or calcium chloride for ice removal.

STUDY OF MANUFACTURING CONTROLS

We continued our investigations to improve manufacturing controls in order to insure a uniform air-entraining cement and were active in the

Engineering News-Record, October 10, 1940.

promotion of field experiments to determine the true value of air-entraining cement in reducing or eliminating scaling of concrete pavements. Projects to which air-entraining cement was furnished were closely followed to determine the relationship between our laboratory control test and the performance of concrete in the field. The performance of some of these projects was reported recently by O. H. Gosswein† and E. F. Young.‡ These are only a part of a large number of experimental highways constructed with air-entraining cements. As in the laboratory concrete made with air-entraining cements, these experimental projects have definitely demonstrated the superior resistance of air-entraining portland-cement concrete to scaling. In addition to showing improved durability, our observations were that paving concrete made with air-entraining portland cement is easier to finish. The finishing can be started and completed sooner than in the case of concrete made with regular cement. In our opinion these savings in cost are also a feature to be considered.

From a thorough study of data developed in our Research Laboratories and by other investigating agencies, and from observations in the field, we believe there are well-developed facts that must be taken into consideration by the cement manufacturer and user, in order to manufacture a uniform air-entraining cement and to obtain the maximum benefits when used in the field. Among these are:

1. The amount of entrained air and not the amount or the kind of air-entraining agent is the key to satisfactory performance.

2. Unit weight or calculated air content of concrete or mortar is an excellent criterion of plasticity and durability characteristics of air-entraining portland cement.

3. A uniform air-entraining portland cement cannot be manufactured by arbitrarily fixing the amount of air-entraining agent to be interground with the clinker. Saponified Vinsol resin produces more consistent air-entrainment with different brands of portland cement than does powdered or flake Vinsol resin. Our experience is that the proper amount of air-entraining agent required at a given mill does not vary much, but among different plants the range is considerable and below and above that now specified in the A. S. T. M. specifications for Vinsol resin—minimum 0.025; maximum 0.045 per cent. The limits for Vinsol resin in cement specifications should be such as to permit the use of saponified Vinsol resin; and, what is more important, a standard mortar test for determining air-entrainment should be adopted and maximum and minimum air-content values established by which means the proper amount of air-entraining agent may be stipulated.

†*Roads and Streets*, Nov., 1943.
‡*Engineering News-Record*, Dec. 30, 1943.

4. Entrained air is in the form of very tiny bubbles acting as highly efficient particles of fine aggregate, permitting a reduction of both sand and water in the concrete mixture. Both should be reduced and the mix proportions adjusted to give the same cement content per unit volume when using air-entraining portland cement as when using regular portland cement.

Since 1938 we have produced a substantial tonnage of air-entraining portland cement. Considering that it is a comparatively new product, we have encountered few difficulties in its manufacture and use. We have aimed to control our air-entraining cements at all of our plants so that they will give in the neighborhood of 3 per cent air in pavement concrete. Experimental concrete placed in Minneapolis streets in 1939 had a weight loss as little as 1.8 lb. per cu. ft. for air-entraining cement based upon the weight of concrete made with regular cement. These streets are now going through their fifth winter of salt treatments showing no scaling on air-entraining cement concrete and bad scaling on adjoining regular-cement concrete.

EVALUATION OF AIR-ENTRAINING PROPERTIES

For evaluating the air-entraining properties in concrete, our Research Concrete Laboratory uses a standard workability test made on a 1:3.8:3.8 mix by weight of saturated surface-dry aggregate with a net water content of 7.35 gal. per sack. The concrete is mixed for 1½ min. in a Lancaster SW-12 open-tub mixer of 1¾ cu. ft. capacity, from which one of the two mixing plows has been removed. Slump and unit weight are determined and the operator notes workability characteristics, such as cohesiveness, smoothness, mobility, coating of paste on aggregate, nonbleeding tendencies, and "fluffiness" of concrete. We consider a cement to have satisfactory air-entraining properties when the concrete has a slump of 5 to 7 in. and a unit weight of 141 to 143 lb. per cu. ft. Field observations over a period of several years show consistent results in a wide range of concretes. Air contents of field concrete fall largely in the range of 3 to 6 per cent with only isolated cases falling slightly under or over this range. Regular cement in this mix has a slump of 2 to 3 in. and a unit weight of about 148 lb. per cu. foot. It should be noted that the laboratory control mix is lean and over-sanded for the definite purpose of exaggerating the air-entrainment so that when the cement is used under conditions of maximum air-entrainment in the field the air content will not be excessive. This concrete test has proven highly successful as a control test for all our plants. It has been used without changes in method or control limits since our first commercial run of air-entraining cement.

MORTAR TEST FOR AIR-ENTRAINMENT

With only one concrete laboratory and several plants, this was not a convenient test due to the delay involved in forwarding of samples and waiting for test results. Because of this we have developed a sand-mortar test for air-entrainment that can be made in plant laboratories and which insures proper control of the amount of Vinsol resin. We are now using this test in all of our plant laboratories, and preliminary results indicate a close parallel with results of the concrete workability test. The mortar test consists of mixing a batch of 500 g. of cement and 2000 g. of standard Ottawa sand by weight with sufficient water to give a flow of 2.4 to 2.9 in. with the Burmister mortar flow trough. Weight per liter of the mortar is determined and percentage of air-entrainment calculated. This method of test has been submitted to Committee C-1 of the A. S. T. M. and is now being actively considered. We believe the incorporation of such a test for air-entrainment, which can be reproduced in different laboratories, into the A. S. T. M. standard specifications will go a long way in reducing the lack of uniformity of some air-entraining cements in concrete.

EFFECT OF AIR-ENTRAINING CEMENTS ON STRENGTH

There is general belief that lower compressive strength is always obtained when using air-entraining cement. Many of these data have been based on fixed mixes, with no adjustment made in the mix proportions. It should be remembered that the entrained air acts as a highly-efficient fine aggregate, and consideration must be given to the increased volume of mortar or concrete resulting from the bulking effect of this addition. When an air-entraining cement is used in the same mix proportions as regular cement and with the same amount of mixing water, the concrete will be leaner and not so strong. Sand and water should be reduced and the cement content adjusted to the same as that for regular cement for a given volume. When we adjust the mix proportions and use the same amount of cement per unit volume with a reduction in the amount of mixing water, air-entraining portland cement will develop about the same strengths as regular portland cement. In lean mixes, 4 sacks per cu. yd., our tests indicate higher strengths with concrete made of air-entraining cement than with that made of regular cement. In rich mixes of 7 sacks per cu. yd., a slight reduction in strength is noted when using air-entraining cement. These differences are due to the fact that lean mixes permit a larger reduction in the water-cement ratio than do rich mixes. A reduction of approximately 1 gal. per sack of cement is possible with 4-sack concrete and only 0.1 or 0.2 gal. per sack with very rich mixes.

Because of some reports that extended mixing times of 10 to 20 min. in closed transit-mix trucks caused excessive air-entrainment, we attempted on a laboratory scale to study this question. The mixer used in the test was a 1-sack capacity revolving horizontal drum type. The two drum openings were fitted with steel covers which could be bolted on to seal the drums. Tests were made with the drums sealed airtight, and with both covers removed. A 6-sack concrete mix was used throughout the tests and mixing times were of 5, 15 and 20 minutes. Included were A. S. T. M. Types I and II portland cements and air-entraining portland cements (containing flake or saponified Vinsol resin) of high and low alkali contents. We were unable to reproduce the reported conditions of excessive air-entrainment. Within the range of 5 to 20 minutes mixing time, of the cements under study the air-entraining cements did not produce excessive air-entrainment.

Questions which frequently arise in the fall of the year are the relative effect of low temperatures and of calcium chloride on concrete made with regular portland and with air-entraining portland cement. A series of concrete tests was made, the data showing that air-entraining portland cement and regular portland cement were affected in the same manner by low temperatures. With calcium chloride, the strengths were increased with air-entraining portland cement as with regular portland cement, and the air-entraining cement with or without calcium chloride held its superiority over regular cement in the scaling test.

The increase in resistance to scaling, using sand of questionable soundness, of air-entraining portland cement in our Hudson experimental road led us to investigate in the laboratory the relative durability of air-entraining portland cement and regular portland-cement concrete with chert aggregates. Chert used was in gravel form direct from river bed. It was received and used in a saturated condition. Little or no improvement in durability resulted from the use of air-entraining portland cement. The over-all picture is in favor of air-entraining cement but results were too inconsistent to warrant any claims for improvement in durability of concrete made with questionable aggregates.

Since 1939, when our laboratory test data were supported by field performance of air-entraining portland cement in our Hudson experimental road, we have been convinced that air-entraining cement would be an important contribution to concrete construction. We felt assured that it would produce scale-resistant concrete surfaces and materially improve our understanding of the numerous factors affecting the durability of portland-cement concrete. During the past four years, the early data have been consistently and conclusively supported by the performance of a large number of field projects and by laboratory studies. There is doubt in the minds of some engineers as to the degree of uni-

formity of the air-entraining properties of some cements. We believe this condition to be temporary and that the application of information now available on control of manufacture and on use in the field will do much in removing any doubts some may have regarding air-entraining portland cements.

Aeration, Offering Improved Concreting, Should be Used with Caution

By HARRY F. THOMSON*
Member American Concrete Institute

In the course of the last three years our company has had occasion to use each of the two common methods of increasing the air content of concrete furnished commercially to various types of building projects; one, by the addition of an air-entraining material to concrete mixed with regular portland cement, and two, by using a cement which had been treated at the mill by intergrinding a resinous material. Concrete mixed by each method has a distinctly greater plasticity than given by the same content of regular portland cement alone.

The air-entraining additive has been introduced to the batch of materials in the central-plant mixer as a dilute solution, to insure rapid and uniform distribution throughout the batch; the material used is a commercial product of the class known to the chemical trade as a detergent, or a foaming agent. Although the quantity used is very small, roughly in the order of only one-half ounce to a yard of concrete, the increase in plasticity for a given cement content is very marked, so that a 4-sack per yard concrete gives an appearance similar to a normal 6-sack mix. The use of the additive increases the slump with the same water content, which in turn permits some reduction in water if similar workability is maintained. The typical weight of a 5¼ sack mix, with water and aggregates adjusted for the same absolute volume and a uniform slump of 4½ in., has shown a reduction from 147.6 lb. per cu. ft. for plain concrete to 143.2 lb. per cu. ft., indicating an aeration of about 3 percent. Although we do not have available a complete comparison of tests, the 28-day compressive strength of the aerated concrete has been substantially the same as for the regular concrete; apparently the increase in strength due to lower water-cement ratio is about offset by a reduction from the aeration.

This type of aerated concrete, which we have furnished in mixes of from four to six sacks of cement per yard, has been very satisfactory with miscellaneous building trade. The feature of improved plasticity appeals to the contractor, especially the man who does not have to buy

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under a strict proportion or cement-content specification and who consequently wants a high workability in a comparatively lean and consequently low-priced mix. So far as we have observed, there has been no change in aeration between the central-mixing plant and the point of deposit after hauls in agitator trucks ranging from 15 minutes to one hour. We have not had occasion to compare the durability of the aerated concrete with the plain concrete.

Our experience with air-entrainment resulting from treated cement has been chiefly on two large projects where this type of cement was specified for portions of the work, although we have also used such cement in deliveries to foundations and walls on smaller jobs. In this case also, the aerated concrete is distinctly more plastic than with the same content of regular cement, and similar slump is obtained with a lower water-cement ratio. For the same 5¼ sack mix as mentioned above, the typical weight with treated cement at discharge from the central mixer was observed as approximately 8 lb. per cu. ft. less than the weight with regular portland cement, indicating an aeration of approximately 5½ per cent. Even with the reduction in water-cement ratio to give the same slump, the compressive strength was reduced an average of about 15 per cent. However, the amount of reduction was by no means uniform with two brands of cement, and other varying conditions found in a commercial operation.

On one of the two large projects which had authorized use of treated cement, the concreting proceeded during the fall and winter months; however, the job returned to untreated cement shortly after the arrival of freezing weather even though the concrete was being delivered in warm condition; whether this change was due to reduction in strength incident to cold weather, as was rumored at the time, or was due to shift in the character of pours, we were unable to learn from the authorities. On the other project, which was carried on during spring months, the treated cement was reported as unsuited for floor-topping due to foaming and tackiness when handled by finishers in conventional manner. On our miscellaneous deliveries of concrete with treated cement to smaller jobs, visual inspection suggested some increase in aeration with length of agitation following central-mixing, but no comparative measurements have been made.

Our observation of concrete mixed with treated cement has brought us to the present conclusion that current cements of that type should not be used on work where it is not possible to have very close supervision and co-ordination of the mixing and placing operations. Thus on a specific job, whether paving or structural, it should be possible to adjust the placing and finishing practices so as to obtain satisfactory construction with the special characteristics of concrete mixed with

treated cement. However, we have also concluded that at the present stage of development, the treated type of cement is not an "all-purpose" cement, and should not be distributed to retail trade promiscuously. It has appeared that any general distribution at this time to retail users who have not been thoroughly informed as to the difference in characteristics as compared to non-treated cement, can lead only to some sad results.

This conclusion is mentioned because there have been instances recently of treated cement being supplied to retail trade without any indication that the material was other than standard portland cement of a given brand; the bags were not even labeled to indicate the presence of the special resinous or plasticizing agent. Such practice has apparently been possible under the emergency specification for portland cement, which did not contain the clause previously included in the A. S. T. M. specification for cement requiring the declaration on the package of the presence of any additive to the normal cement. It is understood that the proper committee is now handling the correction of this apparent omission.

With reference to the possible use of treated cement by a commercial ready-mixed concrete plant, several items must be considered. One point is the effect of a material reduction of strength, like the approximately 15 per cent mentioned above; if a strength specification must be met, then the use of a substantial additional quantity of cement over the content of untreated cement is indicated. Also, if a cement content per cubic yard of concrete is specified, then an aeration of say 5 per cent would require the use of approximately 5 per cent more of treated than of untreated cement. And if the amount of aeration varies with time of agitation, temperature, and other conditions as would be indicated by the saponification between the resinous material and the alkali in the cement, then an accurate control of the concrete as delivered would be very difficult. These considerations all suggest that the intelligent use of treated cement by a ready-mixed operation involves not the mere replacement of normal cement bag for bag, but the application of numerous factors, some of an apparently indeterminate nature.

These remarks are not intended to indicate opposition to the use of air-entrainment. On the contrary, I believe that aeration, properly applied and controlled, offers promise of becoming one of the significant improvements in concrete technique. But in view of the varied experience of different observers, I do not believe any single method of accomplishing air-entrainment should be accepted at this time as a standard or even a preferred method for all types of construction, but that the whole subject should be approached with the caution implied in the slogan, "Stop, Look and Listen."

Milwaukee's Experiences with Air-entraining Cements

By ROBERT A. BURMEISTER*
Member American Concrete Institute

Pavement concretes made with the recently developed air-entraining cements have shown great promise, especially in the matter of durability and resistance to scaling. Since pavement scaling is a serious problem in a northern climate, Milwaukee has followed the development of these new cements with considerable interest. However, the use of these air-entraining cements has introduced new problems in the design and control of concrete mixtures.

In 1940, 1941 and 1942 certain Milwaukee pavements were placed in which the air-entraining cement used was a Vinsol resin-treated portland cement. Late in 1942 comparative tests (R-2)† were run in parallel on standard portland cement concrete and a Vinsol resin-treated portland cement concrete. The street construction project on which these tests were made included curb, gutter, walk, and pavement items. The concrete for curb, gutter and walk was transit mixed and was furnished by a ready mix concrete company close to the job. Concrete for the pavement proper was mixed in a 27 E paver for one minute. A Vinsol resin treated cement (brand 4) was used. For the standard cement concretes, brands 2 and 4 were used. All mixes were designed for a cement content of 5.5 sacks per cu. yd. of concrete. Results on this project were satisfactory—compressive strengths of 6x12-in. test cylinders in excess of 5000 psi at 28 days, moist cured. Cores bored from the pavement at 3 months and tested at three months and at one year showed good increases in strength. The VR concretes generally showed strengths of 80 to 85 per cent of those of the comparable standard portland cement concretes. Durability and scaling studies made in the laboratory and based on freezing and thawing tests and sodium sulfate accelerated soundness tests (similar to those made on concrete aggregates) showed a marked superiority of the VR concrete over standard cement concrete.

In 1943 specifications were drawn up requiring the use of Vinsol resin portland cement conforming to the Tentative Specifications for Treated Portland Cement for Concrete Pavements, A. S. T. M. C 175, type 1 A, for all street construction work excepting base course for asphalt pavements. For pavement concrete, a minimum cement content of six sacks per cu. yd. and a maximum amount of water of 5.7 gal. per sack of cement was specified. Similarly for curb, gutter and walks the same minimum cement content was specified but the maximum

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†See Table 3 for aggregate characteristics, for R-2 series and others described.

water content allowed was 6.1 gal. Estimated compressive strengths of pavement concretes were 3600 psi based on 6x12 inch test cylinders tested at 28 days, moist cured, and for curb, gutter and walks 3500 psi A maximum slump of 3 inches was specified.

War conditions limited the 1943 street pavement program to a number of small projects for which a total of approximately 7000 cu. yd. of VR concrete was placed. This concrete came from six ready mix plants. Five brands of VR cements were used.

MIX DESIGN

Mixes were designed in the City Testing Laboratory for each combination of materials and cement and for the specified minimum cement content, maximum water cement ratio, consistency, and workability. The amount of total aggregate was determined for an estimated air content and the percentage of fine aggregate was determined as required for workability and mortar quality.

Early in the season, extremely high air contents were noted in the concrete on some jobs. These unpredicted high air contents affected the yield, cement factor and of course caused a lowering of strengths. Consequently it became necessary to supplement basic laboratory designs with final designs in the field. In these final field designs the amount of total aggregate was adjusted for proper yield and the percentage of fine aggregate was adjusted to give satisfactory workability. Efforts were made, too, to control the water closely but with air-entrained concrete this proved to be a difficult task—field men were prone to underestimate the slump.

MIXING TIME—TRANSIT MIXER

In conjunction with the studies made on designing proper mixes for the VR concrete, the subject of mixing time was scrutinized as a possible factor in the high air entrainment values. Table 1 presents the results of one test (TM Series) in which a 4.5 cubic yard batch of concrete was mixed five minutes in a transit mixer, when a two cubic foot size sample was removed; the batch was mixed for another five minutes, and a second sample was removed. This process was then repeated for a third five minute period. The great difference between the concrete produced in a five minute mixing period, and that produced in a fifteen minute mixing period, 4560 psi against 2705 psi, both 28 days, made it obvious that when this combination of materials and equipment was used, mixing

TABLE 1—TESTS (SERIES TM) OF TRANSIT MIX PAVEMENT CONCRETE
(Parts A, B, C of one batch, 4.5 cu. yd. using Brand 2 Vinsol resin cement, with sand and gravel aggregate)

		Part A		Part B		Part C	
Mixing	Time Rev.	5 min. 49		10 min. 94		15 min. 131	
Batch wts., lb. per cu. yd.		Wet	Dry	Wet	Dry	Wet	Dry
Admix		0	0	Ditto	Ditto	Ditto	Ditto
Cement		564	564				
F. Agg.		1210	1146				
C. Agg. No. 1		610	602				
C. Agg. No. 2		1055	1033				
C. Agg. No. 3		400	398				
Water, added		194					
Water, total		253					
		4033	3179				
yield, cu. ft.		27.40		28.17		28.46	
cu. yd.		1.015		1.043		1.054	
cement, sacks per cu. yd.		5.91		5.75		5.69	
gal. water per sack		5.05		5.05		5.05	
wt. fresh conc., lb. per cu. ft.		147.19		143.19		141.69	
wt. loss per cu. ft.		7.81		11.81		13.31	
per cent air void		5.62		8.18		9.13	
per cent F. agg. by wt. of total aggregate		36.0		36.0		36.0	
slump, inches		4		5½		6	
workability		Good		Good		Good	
Compressive str., psi		7 day	28 day	7 day	28 day	7 day	28 day
		3210	4620 4235 4825	2055	3050 2885 3170	2015	2635 2735 2750
Average			4560		3035		2705

time would have to be controlled between narrow limits if proper concrete quality was to be maintained. It will be observed that the reason for this difference in strengths was due to increased entrainment of air at the greater mixing period. It might be assumed that if the VR content of this shipment of brand 2 cement had been intended for a one minute mix in a field mixer, it was excessive for transit mixers when their normal mixing procedure was followed.

TABLE 2—TRANSIT MIX TESTS (M SERIES)

(Aggregate, sand and crushed limestone; VR cement brand 5)

Batch number	1		2		3		4		5		6	
Mixer Number	No. 3 5 min.		No. 4 6 min.		No. 3 6 min.		No. 4 9 min.		No. 3 6 min.		No. 4 6 min.	
Batch wts., per cu. yd.	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Admix	0	0	0	0	0	0	0	0	0	0	0	0
Cement	564	564	564	564	564	564	564	564	564	564	564	564
F. Agg.	1310	1254	1310	1254	1310	1254	1310	1254	1310	1254	1310	1254
C. Agg. No. 1	690	680	690	680	690	680	690	680	690	680	690	680
C. Agg. No. 2	1040	1030	1040	1030	1040	1030	1040	1030	1040	1030	1040	1030
C. Agg. No. 3	0	0	0	0	0	0	0	0	0	0	0	0
Water, added	175		181		181		198		200		200	
Water, total	220		226		226		243		245		245	
	3779	2964	3785	2964	3785	2964	3802	2964	3805	2964	3805	2964
yield, cu. ft.	26.77		27.27		26.67		26.19		27.04		27.06	
cu. yd.	0.991		1.010		0.988		0.970		1.001		1.002	
cement sacks per cu. yd.	6.06		5.94		6.08		6.19		5.99		5.98	
gal. water per sack	4.39		4.51		4.51		4.85		4.88		4.88	
Wt. of fresh conc., lb. per cu. ft.	141.19		138.81		141.94		145.19		140.69		140.56	
loss in wt., lb. per cu. ft.	11.25		13.63		10.50		7.25		11.75		11.88	
per cent air void	9.9		11.2		9.2		6.5		9.3		9.4	
per cent f. agg. by wt. of total agg.	42.3		42.3		42.3		42.3		42.3		42.3	
slump, inches	6		3		2		3		4		6	
workability	Good		Good		Good		Good		Good		Good	
Compressive str., psi	7 day	28 day	7 day	28 day	7 day	28 day	7 day	28 day	7 day	28 day	7 day	28 day
	2680	3140	2670	2960	3370	4155	3885	5310	2500	3330	2795	3700
		3125		3290		4125		5320		3435		3795
		2865		2905		3560		5250		3580		3685
Average		3045		3050		3945		5295		3450		3725

VARIABLE VR CONTENT

Tests made on batches of concrete transit mixed for the first day on another project (M Series) showed air entrainment of 13.5, 10.8 and 10.6 per cent with corresponding 28 day strengths of 2585, 2800, and 3315 psi respectively. The fine aggregate was a sand, the coarse aggregate consisted of two sizes of crushed limestone, and VR cement brand 5 was used. The mix was redesigned with less total aggregate, and the amount of fine aggregate was reduced from a nominal 43 per cent to a nominal of 42 per cent by weight of total aggregate. Also to insure close control of mixing time, the transit mixers were driven to the job without revolving the drum. The entire mixing for each batch was then performed on the job. Mixing time was scheduled for 5 to 6 minutes. These transit mixers were loaded to manufacturer's rated capacity of three cubic yards.

Six successive batches were mixed and tested in this fashion with the exception of batch 4 (Table 2). At the end of the 6 minute mixing period in this batch, it was noted that the concrete had a dry, cohesionless appearance and the usual lubricity of VR concrete was lacking. Water was added and the batch was mixed for another three minutes (making a total of nine minutes) after which the concrete appeared to be satisfactory.

A comparison of the six batches shows a considerable fluctuation in concrete quality—the variation in strength from a low of 3045 to a high of 5295 psi is unusual. Air contents are also erratic (Fig. 1).

Since all of the batches were made and tested in a single morning and the aggregates were reasonably uniform in gradation and moisture content and there were only two transit mixers used, the wide divergence in concrete quality appears to be due to variations in the cement itself—variations of the VR content of the cement from batch to batch.

COMPARISON OF COMPRESSIVE STRENGTHS

The primary objective in the 75 series of tests was to compare the compressive strengths of concrete made with the various cements—both standard and Vinsol resin, and Vinsol resin cement plus calcium chloride. These tests were started several months after the close of the 1943 paving season. The mix selected for VR cements was that intended for curb, gutter and walk concrete for which the desired strength was 3500 psi (28 day, moist cured). The mix selected for the comparable standard cement concretes was made with the same nominal cement content, six sacks per cubic yard. In the standard cement mixes, the amount of total aggregate and the percentage of fine aggregate were, of course, higher than those for the VR mixes. Batch sizes were one cubic yard and the mixing was done by a three cu. yd. size central mixer with

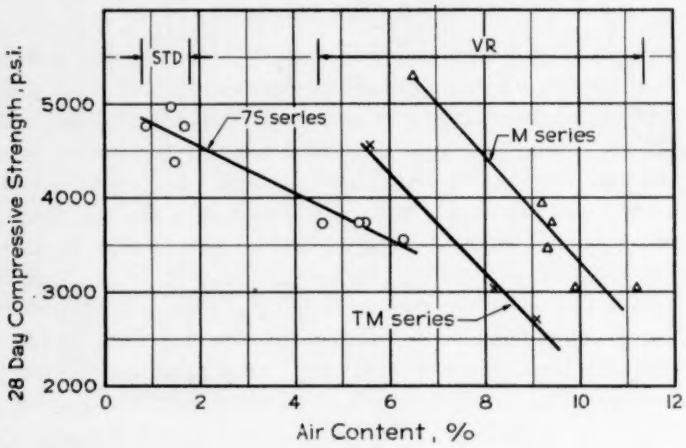

Fig. 1 (above)—Air content-compressive strength relations for various concretes

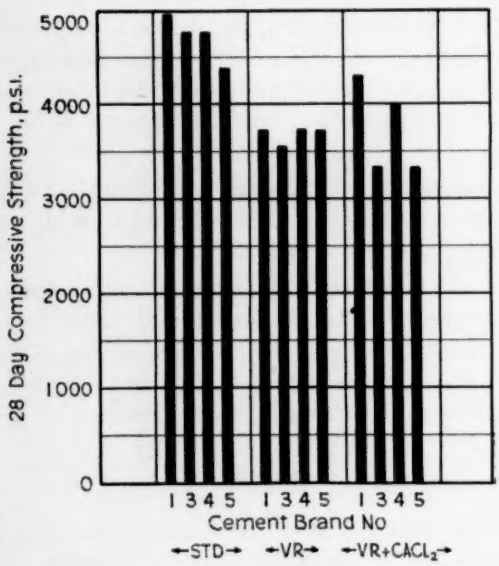

Fig. 2—Compressive strengths of concretes made with various cements (75 series); central mix and agitated 6 sacks cement per cu. yd.

a mixing time of 60 seconds, after which the concrete was discharged into a transit mixer where the concrete was agitated for 15 minutes. Aggregates for physical data tests were sampled daily and for at least every other batch. Specimens will be tested up to 5 years; 3 specimens each test age. A graphical summary of 28 day compressive strengths is shown in Fig. 2, and the relation between air content of concrete and compressive strength—for the aggregates used in this series—is shown in Fig. 1.

TABLE 3—PHYSICAL DATA, AGGREGATES

Fine Aggregate Sieve Analysis Per cent by wt. passing also F.M., SP.G., & ABS.

SERIES	R-2	TM	M	75	Spec.
Key	J	L	J	H (Average)	
⅜"	0	100	100	100	100
No. 4	98	100	99	99	95-100
No. 8	83	89	81	87	
No. 16	66	69	58	67	45-80
No. 30	45	43	36	46	
No. 50	18	13	12	19	7-30
No. 100	3	4	2	6	0-6
F. M.	2.87	2.82	3.12	2.76	
SP. G.	2.67	2.67	2.65	2.64	
ABS	1.1	0.9	1.0	0.8	

Coarse Aggregate

	Gravel	Gravel	Cr. Stone	Gravel	
Key	J	L	M	H	
Sizes*	1 & 2		1 & 2	1 & 2	
	1, 2 & 3	1, 2 & 3			
SP. G.	2.71	2.71	2.71	2.71	
ABS	1.3	1.3	1.1	1.2	

*Note: Size 1, ¼"-¾"; Size 2, ¾"-1½"; Size 3, 1½"-2½"

The compressive strength of concrete made with VR cement brand 1 i. e. 3720 psi at 28 days, compares closely with the strengths obtained with this cement during the 1943 season. For curb, gutter and walk projects, the average strength of 22 6x12-in. concrete test cylinders was 3600 psi. For pavement jobs, the average strength of 24 6x12-in. concrete test cylinders was 3775 psi. In the curb, gutter and walk projects the aggregates were the same as in the 75 series. In the pavement projects, the aggregates also were the same excepting that a No. 3 size crushed limestone was included in the coarse aggregate in the amount of 15 per cent of the total dry weight of the coarse aggregate. The maximum air content recorded for this VR cement during the season and in subsequent tests is 5.5 per cent.

Fig. 3 shows the effect of long-time mixing on concrete made with VR cement brand 1. It is anticipated that 28 day tests will show strengths somewhat higher than usual.

These tests of concrete after long time mixing show also moderate air entrainments (under 4 per cent) for VR cement brand 1 even though two types of mixing were used, i. e. central mixed for one minute, then agitated at 6 rpm, and transit mixed at 13 rpm. In the TM series high air entrainment was obtained with VR cement brand 2 using the same

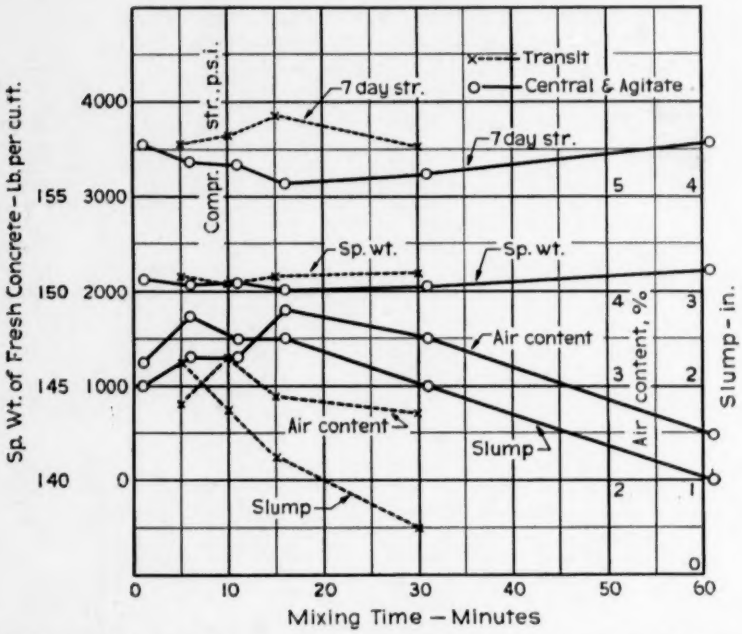

Fig. 3—Effect of long time mixing—VR cement brand 1, 6 sacks per cu. yd. of concrete (75 series)

size of transit mixer (4 cu. yd.) and the same make, however the speed of the transit mixer in the TM series was about 9 rpm.

The slump after one minute in the central mixer was 2¼ in., after agitating it rose to 2¾ in. and then gradually decreased to one inch at the end of 60 minutes of agitation. The temperature of the concrete was 64 F at the beginning of the agitation, at the end it was 66 F—a 2-degree rise in 60 minutes. The slump in the transit mixed concrete was 2¼ in. after 5 minutes of mixing then dropped to ½ in. at the end of 30 minutes of mixing. The temperature of the concrete at 5 minutes was 68 F, at the end of the 30 minute mixing period it was 80 F—a 12-degree rise. The ambient air temperature for these tests was 40 to 44 F.

Further tests with VR cement brand 1 conducted on wetter concretes having initial slumps of 4½ to 6 in. also showed air entrainment of less than 4 per cent

CONCLUSIONS

1. Mixes designed in the laboratory for concrete made with air-entraining cement are subject to redesign in the field—to compensate for actual air entrainments occurring under field conditions.

2. For some cements, possibly those having a large amount of air-entraining agent, mixing time must be controlled between narrow limits. Or, air entraining cements might best be furnished in two types—one for field mixed concrete and one for ready mixed concrete.

3. Cement having an uneven dispersion of air-entraining agent—that is, a variable amount from batch to batch, will cause corresponding variations in concrete quality. With such cement good concrete control is very difficult.

4. Brand 1 VR cement has shown consistently good results throughout the 1943 season. Three other brands recently tested in parallel (75 series) show comparable results although some of them did not do so early in the season.

Air-entraining Cements in Ready Mixed Concrete Industry

By STANTON WALKER*
Member American Concrete Institute

The ready-mixed concrete industry is very much interested in anything having to do with cements and, particularly, in any phase which affects the technic of proportioning, mixing and transporting its product. Air-entraining cements appear to fall in that category.

The interest of the industry was aroused by reports of excessive air-entrainment and excessive reductions in strengths, which were attributed to the ready-mixed concrete operation. The disturbing suggestion has been heard, from authoritative sources, that the ready-mixed concrete operation should not be used with these special cements.

Various theories have been advanced as to the features of the ready-mixed concrete operation which lead to the entrainment of so much more air than has been reported for paving and laboratory mixers. Among the factors suggested as being significant are:

1) The "air-tight" drum of certain types of truck mixers.

2) The comparatively slow, "folding," gentle mixing action of the truck mixer.

3) The relatively long time involved in mixing and agitating during transit.

4) The relatively large size of batch in relation to drum size.

Whatever the merits of these theories—and I can say little with respect to them—it might be reasoned that a different amount of air-entraining agent is needed for each type of mixing unit and for each

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time of haul. If that is so, the problems of concrete control are multiplied many times and the use of interground air-entraining agents becomes impracticable.

We don't know the answers to the many questions presented by this new problem, but we do know that the evidence on them is inadequate and conflicting. The answers must be found—and we are sure that they will be—if the use of such cements is to become general, and I am prepared to accept the evidence that they have merit for many uses. Certainly the ready-mixed concrete industry will not permit the scope of its operations to be limited without exhausting every effort to solve the problem—and in finding that solution we are sure that we will receive complete cooperation from the cement industry and from the users of ready-mixed concrete.

Such quantitative information as I can present at this time comes from a preliminary investigation conducted by a member company of the National Ready Mixed Concrete Association—the Warner Company of Philadelphia. The tests were conducted under the general supervision of Alexander Foster, Jr., Vice-president of the company, and, also, Vice-president of the Association. They were under the immediate supervision of H. J. Knopel, prominent in Philadelphia as a consultant specializing in concrete control problems. I cooperated in the outline and conduct of some of the tests and in the study of the data.

The tests were conducted under laboratory conditions using a 3½S* tilting mixer operated in a normal manner and also in a manner to simulate a truck mixer and agitator. Time will not permit giving the results of the tests in detail. I shall confine myself to a brief summary of the main indications from the five series of tests which have been conducted.

The first group of tests was made for concrete of constant proportions, including water ratio, conforming to requirements for highway mixes in the State of Pennsylvania. All batches were mixed two minutes at 18 rpm. Tests were made on concrete without further mixing and after agitation at 4½ rpm for 15 and 30 minutes. Agitation was performed with the drum open and with the drum closed so as to be air-tight. For the closed drum condition one set of tests was made for concrete agitated under an air pressure of about 10 psi and another agitated under only such pressure as was developed by the mixer action.

The air-entraining cement gave strengths at both 7 and 28 days of about 75 per cent of the normal cement, when there was no agitation. Agitation resulted in the entrainment of additional air resulting in still greater reductions in strength, although there was no significant difference as between the 15 and 30 minute periods of agitation or as between agitation in the open and closed drum, including the closed-drum condi-

*Drum volume, water capacity vertical position 13.5 cu. ft.

tion with 10 psi air pressure. The agitated concrete had a strength about 58 per cent of the normal cement concrete and about 77 per cent of the air-entraining cement concrete which was not agitated.

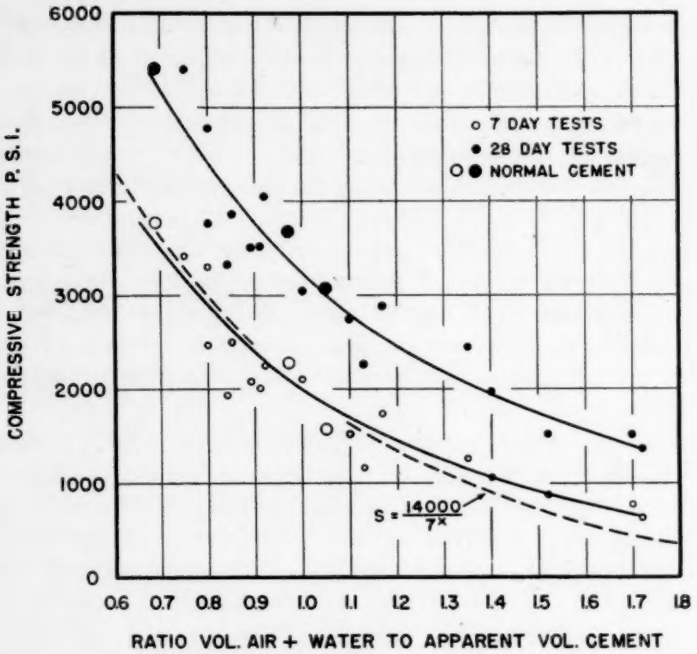
In a second series of tests a number of variables were studied, again with concrete of the same proportions. Concrete mixed 2 minutes in the mixer showed significantly more air and less strength than concrete mixed 5 minutes by hand. Concrete mixed 50 revolutions at 4½ rpm gave about the same results as concrete mixed 50 revolutions at 18 rpm. Batches of different sizes (0.1, 0.2 and 0.3 cu. yd.) indicated less air and higher strengths for the larger batches. Without reciting the results in detail it can be said that air up to 9 per cent was entrained producing strengths 56 per cent of the normal cement concrete which contained about 2.9 per cent of air.

A third series of tests involved cement contents ranging from about 4 to 6.3 sacks per cu. yd. and slumps, for each cement content, ranging from about 2 to 6 in. These tests showed the entrainment of more air for lean than for rich mixes and more air for wet than for dry mixes. Air up to 13 per cent was introduced with comparable reductions in strengths.

These three series of tests were made with the same cement and the same air-entraining agent. Two other series were made, one with another cement and one with another air-entraining agent. Before commenting on them I wish to refer to one diagram (Fig. 1) which, it seems to me, reveals a fundamental relationship.

Fig. 1 shows the 7 and 28-day strength tests for Series 2 and 3 which, it will be remembered, involved different mixes and consistencies as well as different mixing conditions. The strengths are plotted in relation to the volume of air expressed as a ratio to the apparent volume of cement—which will be recognized as an adaptation of the void-cement ratio introduced by Talbot and Richart. A third curve shows a plot of the conventional $S = \frac{14000}{7^x}$ where, in this case, x involves both water and air instead of water alone. It seems to me that these data suggest a fundamental relationship which may be expected to exist in those cases where the air-entraining agent does no more than entrain air—that is, does not influence the hardening characteristics of the cement.

The fourth series of tests involved another cement, with the same air-entraining agent as used in the first three and tested under similar conditions. Much less air was entrained with this second cement and, consequently much less reduction in strength was obtained. However, the data, more limited than those just described, show a relationship between strength and water plus air similar to that just described.



A fifth series of tests involved the same cement as used in the first three series but a dfferent air-entraining agent. These tests differ significantly from those just described in that less air was entrained and less reduction in strength was suffered. However, the data, while somewhat erratic, still show a strength—water + air relationship similar to the earlier group of tests. With respect to this last agent, however, I should point out that I have seen results of tests conducted by a number of other organizations, including one group of tests made using a truck mixer, which indicated actual increases in strength in spite of the entrainment of air.

Just one other point and I have finished. In the tests which have been described, the proportions, except for the fifth series, were constant for a given comparison. That is to say, for a given set of proportions, the cement content per unit volume of concrete decreased as air was entrained. More favorable comparisons between normal cement and air-entraining cement would have been found had the same cement content been maintained and an adjustment in the fine-coarse aggregate ratio made. Nevertheless, the data are of significance in showing the wide range in strengths which may be obtained with a given air-entraining cement concrete for different conditions of mixing. One cannot design to compensate for air and to maintain the same cement content unless he knows how much air will be entrained.

TABLE 1—FREEZING AND THAWING TESTS OF 3 BY 6-IN. CONCRETE CYLINDERS CONTAINING AIR-ENTRAINING AGENTS

Cement Content of Concrete: 5.5 Sacks Per Cubic Yard

Air-Entraining Agent	Water-Cement Ratio, by wt.	Unit Weight at 28 Days, pcf.	Total Expansion During Freezing and Thawing Treatment, millionths per unit		Loss in Weight During Freezing and Thawing Treatment, per cent		Compressive Strength, psi			Loss in Strength Due to Treatment per cent
							After Continuous Storage in Fog at 70°F. to Age		After 654 Cycles of Treatment (Age 288 Days)	
			600 Cycles in Water	54 Additional cycles in 10% $CaCl_2$	600 Cycles in Water	54 Additional cycles in 10% $CaCl_2$	28 Days	288 Days		
None	0.500	156.1	(a)	(a)	(a)	(a)	5330	6830	(a)	100
1	0.475	152.2	1010	1560	1.45	3.20	4890	6500	4320	34
2	0.485	152.0	650	1235	0.95	3.00	4930	6220	4210	32
3	0.470	150.3	635	910	1.00	1.95	4560	5920	4640	22
4	0.470	149.8	245	365	1.10	1.75	4420	5120	4710	8
5	0.460	148.0	225	435	1.15	2.15	3970	5630	5000	11

(a) All four specimens failed between 400 and 500 cycles of treatment.

NOTE: Air-entraining agents interground with cements; all ground to substantially the same specific surface (about 1900 sq. cm per g.)

Entrained Air Beneficial in Freezing and Thawing Tests

By RAYMOND E. DAVIS*
Member American Concrete Institute

Table 1 (p. 551) gives the results of a series of investigations to determine the freezing and thawing resistance of concretes containing five air-entraining agents. Some of these agents were water-soluble and some were insoluble. Study of the table will reveal that all of these air-entraining agents were productive of beneficial results. It is of interest to observe that the total expansion, produced after 600 cycles of freezing and thawing in water or after an additional treatment of 54 cycles of freezing and thawing in a 10 per cent solution of calcium chloride, progressively increases with decrease in weight of concrete or, in other words, with increase in volume of entrained air. The agreement is not as perfect for losses in weight during the freezing and thawing treatment, but the same trend is in evidence. This is likewise true for the loss in compressive strength due to the freezing and thawing treatment.

In these investigations no one air-entraining agent possesses a monopoly in so far as its tendency to improve the resistance of concrete to freezing and thawing is concerned; there are several such agents, some of which are water-soluble.

Field Experiences with Concrete Containing Air-entraining Cement

By GUY H. LARSON†
Member American Concrete Institute

This discussion of concrete containing air entraining agents will be limited to telling something of our field experience with concrete containing Vinsol resin. Tests were made on concrete containing normal and air entraining cements of several brands, and mixed with regular construction equipment on several paving projects. Some of the results presented are a summary of results of regular check tests on the project while others are the results of more detailed investigation. Samples were taken from the batch after it was deposited on the grade, and after making certain tests on the plastic concrete specimens were made for strength and durability tests.

In one series, concretes containing normal and air entraining cement of brands A and B were mixed in a transit mixer as well as in the standard paver. Air entraining cement A contained approximately 0.06 per cent and air entraining cement B contained approximately 0.03 per cent

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†Senior Assistant Engineer Materials State Highway Commission of Wisconsin, Madison.

of chloroform soluble material. Proportions for the normal cement concrete were those used for paving and required 5.4 bags of cement per cubic yard. Proportions for concrete containing the air-entraining agent were adjusted on the basis of laboratory weight per cubic foot tests in order to maintain the cement factor constant. The volume of air incorporated varied with mixing conditions on the job, however, so that the cement factor did vary. In order to observe a richer mix the air-entraining cement content was increased by 25 per cent in another series of tests.

In analyzing the test results the concrete containing normal cement and mixed in the paver was considered as the "standard," and the results obtained with the air-entraining cement or the transit mixer were expressed as percentages of the standard. In the following tabulation values for brands A and B represent the average of 2-3 tests, and for brand C, 12-15 tests.

Cement and Mixer Type	Mixing Time (Min.)	Wt./Cu. Ft. (Per cent of Standard)	28-day Comp. Str. (Per cent of Standard)	Loss in F&T Test (Per cent of Std.)
* A—N Paver	1	Standard (156 lb.)	Standard (4800 lb.)	Std. (44 per cent)
AE "	1	96	87	36
N Transit	25 (approx.)	99	96	100
** AE "	25 "	90	47	23
B N Paver	1	Standard (155 lb.)	Standard (4575 lb.)	Std. (38 Per cent)
AE "	1	98	88	18
N Transit	25 (approx.)	99	87	53
AE "	25 "	96	70	32
C N Paver	1	Standard (155 lb.)	Standard (MR—830)	
AE "	1	96	78	
AE " (ct. increased 25 per cent)	1	—	83	

* A N Paver—Brand "A" normal cement concrete mixed in paver.
**AE Transit—Brand A, air-entraining cement concrete mixed in transit mixer.

It will be noted that as operated on this project the transit mixer tended to incorporate more air than did the paver.

Observations made on the job indicated that concrete having the air entraining agent required less water for a given slump than did the normal concrete. It had a lesser tendency to bleed, and the bleeding decreased as the weight per cubic foot of the concrete decreased. It appeared to be subject to greater variation between batches than was

the normal concrete. There were instances of a difference of 5.5 lb. per cubic foot between batches of the same proportions mixed under like conditions. Operators were not entirely in agreement regarding the relative ease of finishing; however, it was possible to have finishing operations follow placing more closely when working with air entraining concretes. After one or two years' service the concrete containing the air entraining agent has less scaling than does the normal.

Since the tests and specimens were subject to uncontrollable field conditions, the results must be interpreted as representing tendencies and broadly relative values only. Compared to the normal concrete on the basis of the results of these tests and observations, concrete containing the air entraining agent in general was lighter and suffered a loss in strength, but had better resistance to the damaging effects of freezing and thawing. These changes were affected by the amount of the air-entraining agent present, and by the conditions and manner of mixing. It appears there is a definite place for air entrainment in concrete, particularly where exposure is likely to be severe, provided it can be controlled so as consistently to obtain the desired results.

Laboratory and Field Experiences

By J. H. CHUBB*
Member American Concrete Institute

The current A.S.T.M. and Federal Emergency Alternate Specifications for Type I and Type II Portland Cements state that Vinsol resin may be added in an amount not less than 0.025 nor more than 0.045 per cent of the weight of the cement. At present the manufacturer of air-entraining portland cement is confined to the use of one material, Vinsol resin, and the amount added must come within the specified limits.

Laboratory tests and experience in the field with air-entraining portland cements indicate a rather wide variation in the air content of concrete or mortar depending upon a number of factors. That an amount of Vinsol resin within the specification range produces different results with cements from different plants is demonstrated by the test data presented in Table 1.

In this series of laboratory tests the one variable was the cement, that from Plants A and B with and without Vinsol resin. The concrete mix X with normal cement was designed to have six sacks of cement per cu. yd., six gal. of water per sack, and a slump of 2 to 4 in. with ¼- to ¾-in. gravel. This concrete with normal cement from Plant A had a weight of 147.7 lb. per cu. ft. and an air content of 1.25 per cent as determined

*Manager Service Bureau, Pennsylvania-Dixie Cement Corp., New York.

Table 1

	Cement Plant A			Cement Plant B	
Mix by Wt.	X	X	Y	X	X
Gals. per Sack	6.0	6.0	5.7	6.0	6.0
Sacks per Cu. Yd.	6.01	5.86	5.99	6.04	5.98
Slump (inches)	2¾	6¾	4¾	4	5½
Wt. per Cu. Ft. (lb.)	147.7	143.9	144.7	148.4	146.9
Per cent air	1.25	4.24	4.1	1.46	2.28
V. R. per cent	0.000	0.045	0.045	0.000	0.039
Compr. Strength					
7 Days	100	83	97	100	97
28 Days	100	89	100	100	93

Mix X 1-2.23-3.23 ¾ in. gravel 40.9 per cent sand 6 sacks cement per cu. yd. 6 gal. water per sack

Mix Y 1-2.12-3.23 Sand reduced 2.1 per cent of total aggregate and water 5 per cent of Mix X

with a pycnometer. An identical mix but with normal cement from Plant B had a weight per cu. ft. of 148.4 lb. and an air content of 1.46 per cent. These results show good agreement both as to weight per cu. ft. and percentage of air for the same mix but with normal cements from two different plants. If, however, air-entraining cement meeting the specification requirement as to Vinsol resin content from Plants A and B is substituted for normal cements in mix X there is a marked difference in the concretes. The concrete made with air-entraining cement from Plant A as compared with that made with normal cement from this plant shows an increased slump of 4 in., a decrease in weight per cu. ft. of 3.8 lb., an increase of 2.99 per cent in air, a drop in cement content per cu. yd. of 0.15 of a sack and a decrease in strength at 7 days of 17 per cent and at 28 days of 11 per cent. With the same mix and air-entraining cement from Plant B but a slight change is found in the concrete as compared with that made with normal cement from this plant. The drop in weight per cu. ft. is 1.5 lb., the increase in air content only 0.82 per cent, the loss in strength at 7 days 3 per cent and at 28 days 7 per cent, with a drop in cement content per cu. yd. of only 0.06 of a sack.

With the object of maintaining the same cement content per cu. yd., namely 6 sacks, and increasing the strength of concrete made with air-entraining cement from Plant A mix Y was tried. This mix Y as compared with mix X had 5 per cent less water and 2.1 per cent less total aggregate by weight, all the reduction in weight being made in the sand. This change in the mix design had the desired effect. The cement content for the concrete and the strength at 7 and 28 days compared favorably with the concrete made with normal cement although it had an air content of 4.1 per cent and a drop in weight of 3 lb.

Inasmuch as it is considered desirable to have from 3 to 5 per cent air in concretes made with air-entraining cements, the results obtained with cement from Plant A would be considered satisfactory while those with cement from Plant B unsatisfactory because of the low percentage of air.

These laboratory tests and many others indicate that there is a big variation between air contents of concretes made with air-entraining cements from different plants with a Vinsol resin content within the present specification range.

Experiences with job mixed concretes made with air-entraining cements indicate that in addition to variations due to different cements, the air content of the concrete is also affected by the mix proportions, the consistency, character and grading of the aggregates, the type of mixer used, and the mixing time.

Table 2

Column Number	1	2	3	4	5	6	7	8	9
Cement Brand		No. 1 No. 2	No. 1	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Wt. per Cu. Ft.	154.6	153.7	140.2	145	142.4	150.6	149.2	148.0	147.0
Sacks per Cu. Yd.	6.05	6.01	5.49	5.9	5.97	5.91	6.15	6.11	6.04
Gal. per Sack	5.1	5.1	4.89	4.73	4.48	4.65	5.06	4.93	4.97
Per cent sand	37.1	37.1	37.1	29	29.7	32.1	29.8	29.8	28.9
Per cent air	0	0.6	10.7	7.2	9.4	3.6	2.0	3.0	3.7
V. R. per cent	0	0	0.038	0.038	0.038	0.01	0.03	0.038	0.032
Aggregate cut per cent.	0	0	0	4.3	7.5	0			
Water cut per cent	0	0	4	7.3	12.2	8.9			

Two extreme job conditions are tabulated in Table 2. On one job covered by columns 1-6 large drops in the weight of the concrete and excessive air contents were obtained with three different brands of air-entraining cements, all of which had a Vinsol resin content within the specification limits. The coarse aggregate was gravel ¼ to 2 in. material. The sand was coarse having a F.M. of 3.18. The concrete mix set up for the job using normal cement is shown in column 1, Table 2. Assuming no air in the concrete the estimated weight per cu. ft. would be 154.6 lb. for the cement, water, and aggregate contents as shown in column 1. Using normal cements brands 1 and 2 this mix design gave concretes that by weight tests made on the job averaged 153.7 lb. for each cement and had a satisfactory slump of about 2 in. (see column 2, Table 2.) This weight per cu. ft. for the concrete indicated a cement factor of 6.01 sacks per cu. yd. and an estimated air content of 0.6 per cent. With the same batch weights for cement and aggregates as with normal cement brands 1 and 2, but about 4 per cent less total water and air-entraining

cement brand 1, the resulting concrete (column 3) weighed only 140.2 lb. per cu. ft., had a calculated air content of 10.7 per cent (based on this weight), a cement factor of 5.49 sacks per cu. yd. and 4.89 gal. of water per sack of cement. The slump averaged about 4½ in. for this concrete. An unsuccessful attempt was made to reduce the air content to not over 5 per cent and increase the cement content to around six sacks per cu. yd. Column 4 shows the adjusted mix when using air-entraining cement brand 1, and column 5 the adjusted mix with cement brand 2. Other air-entraining cements were tried out but the air content of the concrete was invariably too high and it was finally decided that on this job it was impossible to obtain concrete of the desired weight, air content, and strength with air-entraining cements containing even the minimum amount of Vinsol resin permitted by A.S.T.M. or Federal specifications.

To obtain concrete of the desired 149 to 151 lb. per cu. ft. air-entraining cement brand 3 was used having only about 0.01 per cent by weight Vinsol resin. With this cement the results shown in column 6 were obtained. The average weight per cu. ft. on this concrete was 150.6 lb. with a calculated air content of 3.6 per cent. Batch weights for cement and aggregates were the same as where normal cements were used but the total water was reduced 8.9 per cent, the sand content reduced to 32.1 per cent as compared with 37.1 per cent, and the concrete had approximately 0.1 of a sack less cement per cu. yd.

Columns 7-9, Table 2, show results on a construction job where three different brands of air-entraining cements were used and the air content of the concrete was low as compared with that for the job covered by columns 1-6. The gravel was graded ¼- to 2-in. material, the sand was rather fine grained having a F.M. of 2.48 with about 2 per cent retained on a No. 8 and 12 per cent on a No. 16 mesh.

The job was started with air-entraining cement brand 5, and the results obtained on this concrete are tabulated in column 8, Table 2. With cement brand 4 and the same batch weights for cement and aggregates it was necessary to use a little more water with this cement to obtain concrete of the desired slump. The resulting concrete (column 7, Table 2) weighed a little more, had less air, and a little more cement per cu. yd. With cement brand 6 (column 9, Table 2) concrete with a higher air content, the lowest weight and the lowest cement content was obtained.

These laboratory and field tests are presented as indicating the necessity of changing the present A.S.T.M. and Federal specifications for air-entraining portland cements if predictable, concordant results are to be obtained with different brands of cement and under variable job conditions.

Effect of Air-entraining Agents on Pumped Concrete

By R. T. SHERROD*
Member American Concrete Institute

There has been some question of whether or not concrete containing air entraining agents can be handled by pumping methods. Such concrete has been pumped with excellent results under our personal observation on some half dozen projects. There has been but one unfavorable experience with which we are familiar.

In this instance, a considerable volume of concrete had already been pumped before the cement was changed from standard portland to one treated with an air entraining agent. Trouble was immediately encountered with the pump. It is significant that this trouble was reflected right on down the line, with the cement handling equipment, with the concrete after it had been placed in the forms, with the test cylinders and so on. After a period of three or four weeks use of the air entraining agent was discontinued.

Similar reactions on a few occasions have followed a change of standard cements from different mills. They have also been experienced in a change from standard to high early strength cements and vice versa.

Changing from one type of cement to another has no perceptible effect on the pumpability of most concrete mixtures. In rare instances, however, switching from a standard to a high early strength cement has improved pumpability to a marked degree. Just about as often it has had an opposite effect. These variations from the normal can usually be traced to the over-all coarseness of the mix.

In the light of such incidents, and in the knowledge that air entraining concretes have been pumped very successfully elsewhere, it seems probable that other factors than the presence of an air-entraining agent might have contributed to the difficulty on the job previously cited.

Where we have observed pumps in action with air entraining concretes, the capacity of the machines has been normal, parts wear has been average, and no pipe line trouble has been encountered. The only deviation one way or the other from normal pumping reactions has been a somewhat more pronounced evidence of internal expansion as the concrete reaches the end of a long pipe line. (At this point the author showed a short motion picture in which this symptom was observed in work on a Chicago jetty on Lake Michigan last summer.)

The first step in the rehabilitation of the pier was to cut off the old wood piles and sheeting flush with the top of the walers. Two courses of selected capstones are then placed in position on top of the rip-rap fill, being held to a fairly close tolerance for line and grade. The cap-

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stones were spaced 6 to 12 inches apart on all adjoining sides and consolidated into monolithic blocks, by puddling concrete between the spaces and maintaining the outside lines with a concrete berm along each side.

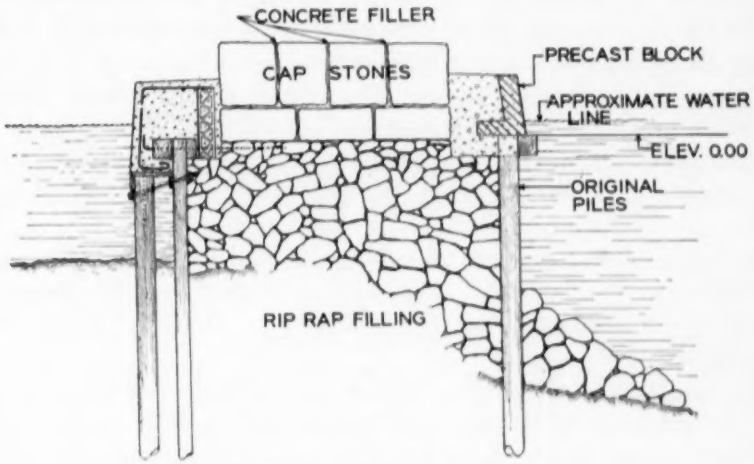

Fig. 1—Rehabilitation of a Chicago pier

Concrete was puddled into the spaces between the stones and spouted into the berms. The mix was heavily sanded because poured into 12 to 15 inches of water in the bottom of the form by the advancing slope method. The pictures show the concrete as quite normal as discharged from the pipe.

The concrete was mixed in a paver spotted near the edge of the existing beach and relayed by boom and bucket to the hopper of a single cylinder pumperete installed on the pier.

The mix was of 1½-in. gravel aggregates with 43 per cent sand and 6 bags of cement, treated with .04 per cent of Vinsol resin. With approximately 6 gals. of water per bag, the average slump was 4 in. at the mixer.

The area encompassed by the pier will become the site of a sand-fill bathing beach. The riprap fill in the structure is secured by crushed stone banked against the outside sheeting.

In delivering the concrete the pipe line was elevated on low horses near the end for convenience in distributing the concrete.

In hot weather, and especially with surface dry aggregates, a slump loss of 1 to 2 in. per 1000 ft. of pipe is normal.

Attention is directed to a continuance of movement in the concrete between impulses of the pump. It is caused, in part, by momentum

and partly by the internal expansion of the concrete. The same condition exists with almost any plastic concrete being pumped a long distance, but it was somewhat more pronounced on this work than is usual. The column of concrete in a long pipe line is subjected to considerable pressure at the pump. As the load is picked up by each power stroke of the piston, the concrete is compressed to a variable extent because of the air interspersed throughout the mix.

However, as the concrete column advances this pressure steadily decreases until it is entirely dissipated at the end of the line. It is obvious that even the slightest pressure near the discharge would cause the concrete to be ejected in spurts rather than "lobbing out" as in this work.

As the pumping pressure eases off, internal expansion returns the concrete to its original state. It is well established that this compaction is beneficial to the concrete. Its workability, if affected at all, is usually improved.

The aerated concretes falling within our pumping experience have all been 5- and 6-bag mixes with sand factors ranging from the low side to the heavily sanded conditions just reviewed. The different mixes have ranged from a stiff to a sloppy consistency.

Vagaries result from blending air entraining agents with different types and combinations of cements and aggregates, but they will doubtlessly be more completely controlled as time passes. In so far as pumping these mixtures is concerned, it is our present conclusion they will register about the same variations now experienced with general purpose concrete.

Air-entraining Agents in Ohio Highways

By J. F. BARBEE*
Member American Concrete Institute

Air-entraining agents were first used by the Ohio Department of Highways in its test road, built in 1940, a report of which is given in the Proceedings of the 22nd Annual Meeting of the Highway Research Board. The principal features of the forty-nine test sections on this project were the cements and combinations of different cements manufactured with and without air-entraining agents.

Freeze and thaw tests on cores drilled from this project indicated a marked resistance to freezing and thawing for all concrete having a loss in unit weight of two or more pounds per cubic foot, regardless of the air-entraining agent used. The results of the tests obtained on this

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project, together with other laboratory tests conducted in the summer and fall of 1941 which indicated an increased resistance to the development of surface scale due to the use of chlorides for snow and ice removal, resulted in the Department placing under contract early in 1942 four pavement projects in which Vinsol resin cement was specified to be used in the concrete.

One of these projects and part of another were under traffic during the winter of 1942. One developed a slight scale in the gutter adjacent to a monolithic curb while no scale developed on the other project.

Early in 1943 the Ohio Highway Department issued change orders requiring the use of Vinsol resin cement or the use of a Vinsol resin-sodium hydroxide admixture in all concrete pavements then under contract which were not at that time virtually completed. All contracts let since then have also required the use of Vinsol resin.

Pavement concrete (6 sacks of cement per cu. yd.) containing Vinsol resin was placed on 43 projects during the past year. Up to December 1, the 7-day cylinder strengths on these projects averaged 3572 psi and the 28-day strengths averaged 4446 psi. The average of more than 600 7-day beam tests received at the laboratory to date from these same projects was 612 psi. Pavement concrete, of the same cement factor but not containing Vinsol resin, placed during 1942 had an average 7-day compressive strength of 3932 psi, a 28-day compressive strength of 5394 psi, and an average 7 day beam strength of 728 psi. These data indicate that the use of Vinsol resin caused reductions in both compressive and flexural strengths at these ages of approximately 15 per cent.

The use of Vinsol resin in the concrete regardless of whether it was introduced with the cement or in a solution generally resulted in an oversanded mix. For sand and gravel mixes, a reduction made in the amount of fine aggregate which was sufficient to produce the correct yield generally resulted in a satisfactory proportion of fine aggregate. The decrease in the amount of fine aggregate also resulted in a slight reduction in the water-cement ratio. When limestone and slag were used as coarse aggregate it was found that a correction for the increased yield of the concrete could not always be made in the fine aggregate alone, but that partial reductions had to be made in both the fine and the coarse aggregate in order to retain the proper proportions of aggregates in the mix.

The use of the Vinsol resin-sodium hydroxide solution did not contribute any additional difficulties other than those that would be caused by the use of any admixture in the field. The concentration of the solution varied, of course, with individual job conditions. Generally a solution providing 0.007 per cent to 0.010 per cent Vinsol resin by

weight of cement was sufficient to give approximately a four-pound reduction in unit weight when compared with the same concrete without the solution. This is about one-fourth of the Vinsol resin that is required to produce an equal weight loss when it is interground with the cement.

The Department also built during the past year three pavements using high-early-strength portland cement with a Vinsol resin-sodium hydroxide solution. Satisfactory results were obtained with this combination, although the strengths developed were, of course, lower than those which would result from the use of high-early-strength cement without the Vinsol resin solution. However, the combination did permit the pavement to be opened to traffic at an earlier date than does ordinary portland cement with Vinsol resin.

Several of the projects now under construction in Ohio require a cement factor of 6½ sacks of cement per cubic yard. Concrete made with the 6½ sacks and Vinsol resin is even more fluffy than that which contains only 6 sacks. We have found that in order to reduce the sand sufficiently in sand and gravel mixes of this higher cement factor, it is often necessary to remove more sand from the mix than that which will just correct the over yield.

While the use of Vinsol resin permits the speeding of finishing operations in the summer, this condition does not hold true when cooler weather arrives. In cool weather the finishing operations were conducted at approximately the same time as for cements without Vinsol resin. The use of two pounds of calcium chloride per sack of cement integrally in the Vinsol resin concrete has been permitted during the colder months. The use of the chloride did not in any visible way effect the workability of the concrete gained by the use of the Vinsol resin. Apparently its only effect was to accelerate the setting time and make it possible to finish the concrete more promptly.

The concrete on our projects made with Vinsol resin cement or Vinsol resin-sodium hydroxide solution has been easy to handle, cohesive and workable. No particular difficulty in finishing has been experienced except for a tendency of the concrete to become sticky. When it is finished promptly, generally one to two passes of the finishing screed, followed by a light floating to remove the screed marks prove sufficient to produce a dense uniform surface. At times the concrete is very sticky. Often this has been found to be due to an excess of sand in the mix. When the batch weights are changed to correct for this condition the stickiness is generally eliminated. Satisfactory results in finishing have also been obtained by increasing the number of oscillations of the finishing machine screed per linear foot of travel. This usually eliminates

the pock marks or tearing of the surface caused by the concrete sticking to the finishing machine screeds. This torn condition can often be overcome also by using steel floats or steel-shod floats for hand finishing. They generally give better results than wooden floats. In any event for summer work all finishing operations should follow as closely behind the finishing machine as possible. This is due to the fact that there is little free water on the surface for lubrication during the finishing operations and when these are not carried out with a minimum of delay, the drying of the surface hinders satisfactory finishing. This situation has been found to be more critical at high temperatures, when the relative humidity is low or when the wind is blowing at a high velocity. The use of Vinsol resin enables the concrete finishers to follow the mixer more closely and long waits and overtime for finishing at the end of the day are avoided.

Our experience to date indicates that the use of Vinsol resin to produce concrete with a loss in weight of three to five pounds per cubic foot introduces no construction difficulties which can not be overcome practically. All difficulties encountered so far, have been overcome with minor changes in design and construction procedure. The problem resolves itself into simply one of adjusting the concrete mix and the construction practices to the characteristics of the material and involves no more radical changes than might be necessary due to many other changes which are frequently encountered in job conditions.

Air-entraining Agents Not a Cure-all

By F. V. REAGEL*
Member American Concrete Institute

Most of the claims for the advantage of greater than normal air-contents in concrete have been made in connection with prevention of a progressive scaling of pavements and other thin slabs. This form of deterioration, caused by repeated freezing and thawing, results in a disintegration of the mortar, and is accelerated by the use of calcium chloride for ice removal.

In Missouri pavements, deterioration definitely attributable to freezing and thawing, is associated only with use of certain coarse aggregates. The failures are not preceded or accompanied by scaling; and apparently there is no particular mortar disintegration. Despite this difference in the manifestation of deterioration under freezing and thawing, certain properties imparted to concrete by entrapped air were considered as possible antidotes to failures resulting from use of these coarse aggre-

*Engineer of Materials, Missouri State Highway Dept., Jefferson City, Mo. Mr. Reagel's discussion did not have convention presentation, having been received by the Institute late in March.

gates. Some of the results of the investigation of this possibility are shown in Fig. 1 and 2.

Each square of Fig. 1 shows results of freezing and thawing tests on concretes containing above-normal quantities of air, compared with concretes containing the same materials but with normal quantities of air. Abnormal air-contents were obtained by using cement ground with Vinsol resin. The percentage loss in dynamic modulus is plotted against the number of cycles of freezing and thawing. Letters on the curves designate the coarse aggregate used and the numbers give the approximate air content of the plastic concrete. It is obvious that with chert aggregates A and C there is little additional resistance to freezing and thawing gained through entrapment of air. In the case of the limestone aggregates B and D, a distinct increase in freezing and thawing resistance is noted. It should be stated that pavements containing

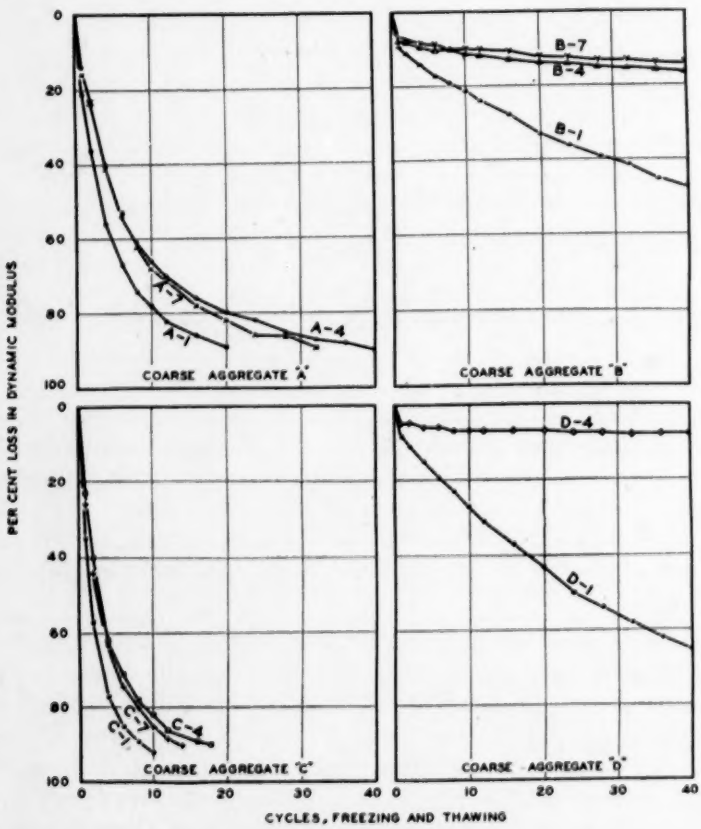

Fig. 1—Effect of Vinsol resin on resistance of concrete to freezing and thawing as measured by per cent loss in dynamic modulus (Missouri procedure).

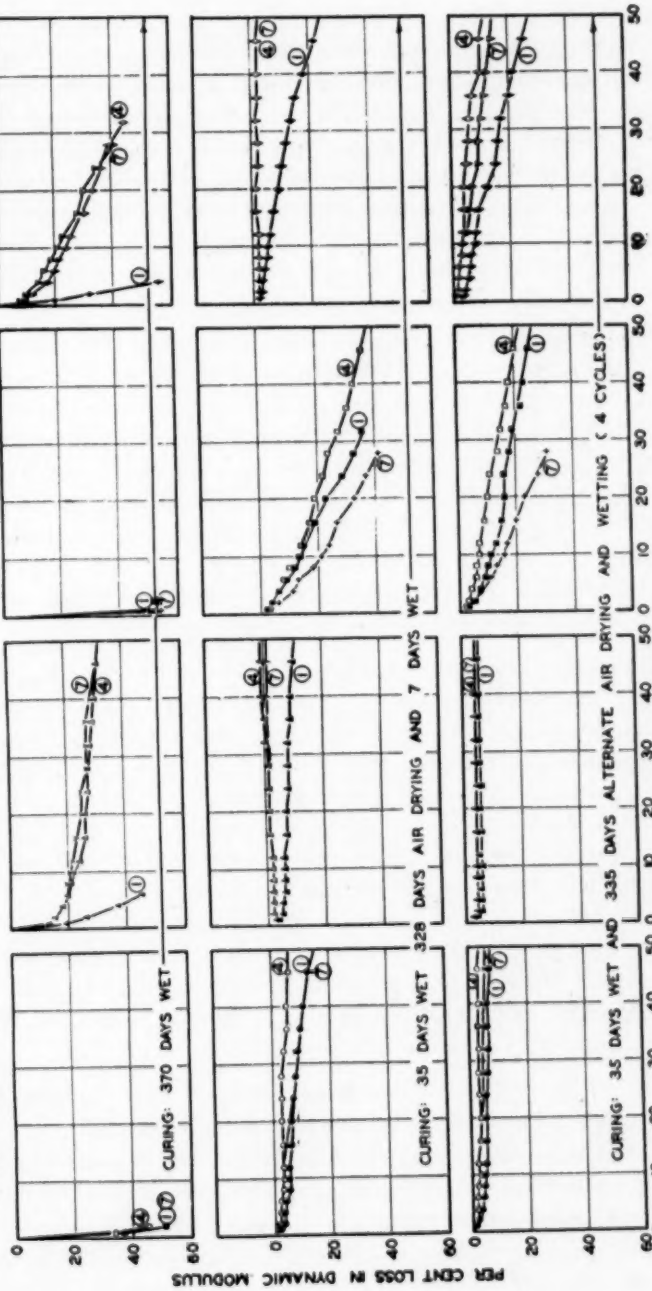
COARSE AGGREGATE 'A'
COARSE AGGREGATE 'B'
COARSE AGGREGATE 'C'
COARSE AGGREGATE 'D'
CURING: 370 DAYS WET
CURING: 35 DAYS WET 328 DAYS AIR DRYING AND 7 DAYS WET
CURING: 35 DAYS WET AND 335 DAYS ALTERNATE AIR DRYING AND WETTING (4 CYCLES)
PER CENT LOSS IN DYNAMIC MODULUS
CYCLES FREEZING AND THAWING

Fig. 2—Effect of Vinsol resin on resistance of concrete to freezing and thawing as measured by per cent loss in dynamic modulus (Missouri procedure—370 days).

aggregate B have an excellent service record in so far as resistance to freezing and thawing is concerned, most of the deterioration in the older pavements having resulted from structural breakage due to loads and inadequate subgrade support. Because of the known effect of abnormal air content on the flexural strength of concrete (in this series of tests increasing air content from 1 to 4 per cent and 7 per cent decreased the flexural strength 7 per cent and 18 per cent respectively) discrimination in the use of larger than normal air contents, even with limestone aggregate, is warranted; particularly if the materials combination has been previously used without showing lack of resistance to freezing and thawing.

Fig. 1 showed results on concrete kept thoroughly wet for 35 days and then subjected to continuous freezing and thawing. To learn what would happen to older concretes having different moisture contents at the time of initial freezing, duplicate specimens were fabricated and cured for 370 days by one of three methods: (a) continuous soaking, (b) continuous drying for 328 days with 7 days soaking just prior to freezing, and (c) 4 cycles of alternate drying and soaking, each cycle consisting of 56 days drying and 28 days soaking. These specimens were then subjected to the same freezing and thawing procedure as those previously described, with the results shown in Fig. 2.

It is evident again that abnormal quantities of air were of little or no benefit to the concretes containing chert aggregate, regardless of the moisture treatment prior to freezing. For the concretes containing limestone aggregate, entrapment of additional air was beneficial under all moisture treatments, although the magnitude of the improvement was small in some instances. One of the most striking points indicated is the radical improvement shown by the B concretes of abnormal air contents which had been soaked during the entire curing period. As previously stated pavements containing this aggregate have never evidenced any lack of durability, but it is evident that stretches of such pavements, which were to be subjected to long periods of saturation followed by freezing and thawing, might be greatly benefited by entrapped air in quantities greater than normal.

Our present attitude toward concrete of abnormal air-content, based only on laboratory tests, may be summarized as follows:

(1) Such concrete in the plastic state is 'fatter,' is more easily placed, and has less tendency to bleed than comparable concrete of normal air-content; in the hardened condition there is a reduction in flexural strength and dynamic modulus of elasticity; the thermal coefficient of expansion is not affected.

(2) Abnormal air-contents cause no appreciable improvement in the

durability of concrete containing chert aggregates, use of which has resulted in pavements lacking in this quality.

(3) Abnormal air-contents improve the durability of concrete containing either mediocre or good limestone aggregate.

(4) In any case where the use of abnormal air-contents seems warranted, the resulting reduction in flexural strength should be balanced against the need for improvement in durability or any other desirable qualities imparted by higher air-contents.

Concluding Summary

By F. H. JACKSON

In concluding my opening remarks on the subject of air-entrainment, I summarized what seemed to me to be the crux of the problem by asking two questions. First, is the improvement in durability which results from the use of the so-called "air-entraining agents" due solely to increased air content or are there other possibly less obvious reasons and second, if the introduction of an optimum quantity of air *is* the all important thing, how can this best be accomplished for a particular job? The first question appears to have been answered definitely in the affirmative. In fact, I find no negative opinion on this point among the contributors who, without exception, appear to take it for granted that improvement in both workability and durability is due entirely to an increase in air voids and to nothing else.

As regards the second question, I find the discussions of value chiefly as emphasizing the need for additional work on the many practical problems which arise from attempts to apply this principle to everyday job operations. So far as the 13 contributors to the discussion are concerned, there seems to be general agreement as to the nature and importance of the variables which need to be controlled. For example, several of them discuss the effect of long continued mixing, such as is common practice in the ready-mixed concrete industry. Data are presented both for and against the argument that continued mixing introduces excess air. However, all agree that too much air may be entrained if the conditions are right and that this fact poses a problem which must be solved before general acceptance can be given to the use of air-entraining cements in the manufacture of ready-mixed concrete.

The general effect of increased air content on strength and yield is recognized. Several contributors also stress the importance of redesigning concrete containing entrained air by correcting for the over yield and thus compensating partially, at least, for the decrease in strength

which almost invariably accompanies increase in air voids. Opinions differ as to the extent to which strength can be maintained by redesigning the mix and also as to whether strength lost through the introduction of air can be recovered merely by reducing the absolute volume of sand in the mix by an amount equal to the increase in the volume of air; in other words, by maintaining the cement factor constant.

Mr. Reagel calls attention to the fact that the use of an air-entraining agent will not improve the quality of concrete containing certain types of unsound coarse aggregate, a conclusion which has been verified by other investigators. This conclusion is of importance in illustrating the fact that an air-entraining agent should not be relied upon as a cure-all either as regards defective materials or methods of construction. This point is emphasized by other contributors, including Mr. Swayze.

The effect of sand grading and richness of mix is pointed out by Mr. Kennedy and others. Mr. Kennedy describes a very interesting demonstration of the plasticizing effect of an air-entraining agent on a mixture of sand and coarse aggregate containing *no* cement. After several minutes' mixing, the mass developed all of the characteristics of a well designed concrete mix. I can personally vouch for the accuracy of these observations because I was present when this batch of "concrete" was mixed. The lesson is, I believe, obvious.

Several of the contributors, including Messrs. Lindsay and Swayze, discuss variations in air content resulting from the use of different cements in which the "air-entraining" agent was interground at the time of manufacture. It is pointed out that some cements which contain relatively small amounts of air-entraining materials will produce substantially greater amounts of air in the concrete than will other cements containing relatively larger amounts of such materials. It is obvious that, until this variable is controlled, the difficulties of insuring the "optimum" air content on the job with cements containing interground air-entraining agents will remain. In this connection, Mr. Swayze calls attention to the proposed change in the A. S. T. M. specifications for air-entraining cement which puts the air-entraining characteristics of the cement on a performance basis rather than by definitely limiting the amount of the interground addition. It should be pointed out that while this proposed change will tend to put all cements on the same basis insofar as their ability to entrain air under a standard test condition is concerned, it does not solve the problem entirely. There still remains the question of field adjustment to take care of variables other than the cement, such as type and grading of aggregate, type of mixer, length of mixing time, etc. It must be confessed that, insofar as these problems are concerned, the contributors to this discussion have in general not been very helpful. Perhaps it is too much to expect at this stage. How-

ever, these are all questions of detail which must and will be answered. I am in agreement with the thought expressed by all of the contributors that the principle of air-entrainment is here to stay and that in the future we may expect a much more general application of the idea than has so far been attempted.

One subject touched upon in the introduction was not mentioned by any of the contributors. I refer to the effect of air-entrainment on bond with steel. So long as the use of air-entraining agents is confined to pavements this question has little significance. However, in the case of structural concrete the question of bond is important. Apparently few data are available on this point. This is extremely unfortunate because the absence of such data will unquestionably delay the application of this principle to the construction of highway and other bridges in northern regions where the use of air-entraining agents would be distinctly advantageous from the standpoint of resistance to weathering.

Although the session was intended to cover "air-entraining agents" in general, most of the discussions centered around the use of air-entraining cements, that is, cements in which the addition is interground at the mill. Messrs. Barbee and McPherson both discuss the alternate procedure of adding the air-entraining material to the batch at the time of mixing, the control being the incorporation of a definite amount of air as evidenced by measuring the drop in unit weight. Mr. Barbee states that the use of such an addition at the mixer did not contribute any additional difficulties other than would be caused by the use of any admixture in the field.

After reviewing this whole subject in the light of the latest developments as reflected in the various papers presented at this session, I do not believe that I can conclude this discussion in any better way than by repeating the following question which I asked in the course of my opening remarks: . . . . "in view of these uncertainties is it not more logical to add the air-entraining agent at the mixer, varying the quantity as needed on each job in order to secure the required amount with the materials at hand and under the practical working conditions which apply to that particular job?

Discussion of the contributions to this symposium should be submitted in triplicate to the ACI Secretary before September 1, 1944, for publication in the JOURNAL Supplement concluding Proceedings V. 40.

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Discussion of a Symposium:

Concretes Containing Air-entraining Agents*

By M. SPINDEL†

In my discussion of a paper by H. L. Kennedy "The Function of Entrained Air in Concrete"‡ I remarked that the pendulum was just swinging excessively towards a very high percentage of air voids in concrete and that too much entrained air might prove to be as detrimental to the quality of concrete as was an excessive amount of water. I wished that we might soon reach the final state of "concretes designed as to the latest development with well balanced limitations for the water-cement ratio and the air-cement ratio as well," and I mentioned that it would be advantageous to show the percentages, by absolute volumes of cement, aggregates, water, and air, the ratios between them, and some properties of the concrete owing to these ratios in a single diagram, such as my 4-matter parallelograms for cement and concrete. The essence was to warn my colleagues that "only admixtures should be used for which the advantages outweigh very much the disadvantages or which are known to have no disadvantages at all."

From the many excellent contributions to the Symposium I was glad to see that at present the pendulum is not being pushed in one direction only, since there were some very cautious views regarding the effect on the percentage of air caused by the various admixtures, cements, and aggregates and their proportions, by the percentage of water, by the type and the time of mixing, transporting and placing the concrete, etc. The etc. means that there are still some important problems to be solved and questions to be answered, which have been put forward by the Chairman.

First of all I was glad to see that the strengths of concrete were not overlooked and that the effect of entrained air on the strengths was shown both in tables and in diagrams. In the paper by Stanton Walker the "compressive strength is plotted in relation to the ratio vol. (air +

*ACI JOURNAL June 1944; *Proceedings* V. 40, p. 509 as presented at the Institute's 40th Annual Convention March 1, 1944.
†London, England.
‡ACI JOURNAL (Supplement) November, 1943.

water) to apparent vol. cement" according to the formula by Talbot and Richart. Another curve shows "a plot of the conventional $S = \frac{14000}{7^x}$ where in this case x involves both water and air". The above "fundamental relationship" has been stated by Mr. Walker to be true also with entrained air both when its percentage was high or low but he mentioned also some "tests conducted by a number of other organizations which indicated actual increase in strength in spite of the entrainment of air". From the above we may see that we shall have to deal again very thoroughly with the relation between strength and the ratio vol. (air + water) to vol. cement.

M. R. Feret had developed on this basis his well known formula

$$B = K\left(\frac{C}{1-S}\right)^2$$

in which B = compressive strength in kg per cm²,
K = factor depending on age, strength of cement, etc.
C = percentage of cement in absolute volume.
S = percentage of sand and coarse aggregate in absolute volume.

The above formula is based on the same principle as that by Talbot and Richart mentioned before.

Since 1918 some formulas have been developed, at first by D. A. Abrams and then by Bolomey, Graf etc. according to which the compressive strength depended on the water-cement ratio only, without any regard to the actual percentage of air in the fresh made concrete, and there were also other formulas developed by the E. T. H. Zurich and by this writer, the latter again was based on the principles by Feret or Talbot and Richart.

The various formulas for the compressive strength of concrete have been dealt with in several papers submitted to the Amsterdam Congress of the I.A.T.M. in 1927. In my discussion of the paper by M. R. Feret (Congress book II, pp. 135, 136) I pointed out that it was not enough to plot the various relations, for example the compressive strength to the cement-aggregate ratio, to the water-cement ratio etc. each independantly but that we must be in a position to see the percentages by absolute volume of all four components of concrete, i.e. cement, aggregate, water, and air, their mutual relations in relation to strength etc. in a single diagram and that was the four-matter parallelorgram which I developed at first for the four main components of portland cement and then in the same way for the four components of concrete.

In that discussion and later in many papers, especially in *Beton u Eisen* 1928, Nos. 1 and 2, 1931 Nos. 1 and 2, 1935 No. 17, I showed

how the manifold relations and properties of concrete could be represented in the four-matter parallelogram, for example the fineness modulus of the aggregates and the percentage of water necessary for each fineness modulus and for the cement, both separately and for their various proportions (cement-aggregate ratios) for the moist, plastic and fluid consistency of concrete. The necessary percentages of water have been obtained graphically in points of intersection of straight lines which were the same as those obtained by D. A. Abrams from his numerous well known tests. Further the density and the specific gravity of the concrete for all possible mixes with and without air voids could be seen by straight contours in the parallelogram and above all the compressive strength according to all known formulas could be read off immediately for every mix possible.

Still all the forementioned advantages are less important than the great service the four-matter parallelogram may give both in the laboratory and in the field when, as to M. A. Swayze, "For any use whether it is in highways, reinforced concrete, or whatnot, the user should by all means redesign his mixes accordingly" and especially when, as to R. A. Burmeister, "Mixes designed in the laboratory for concrete made with air entraining cement are subject to redesign in the field—to compensate for actual air-entrainments occurring under field conditions."

In my opinion the many "unsuccessful attempts" in this direction were due first to the many causes which effect the amount of entrained air and make it a matter of great uncertainty, especially when the air-entraining agent is added in the cement factory during the grinding of the cement instead of being added on the job where it could be regulated according to the special circumstances and the needs of the job. To a certain degree the unsuccessful attempts might be due also to the many mathematical calculations necessary for designing and redesigning the various mixes having a component with such an uncertain percentage as the entrained air still appears to be. On the occasion of designing the percentages of the various raw materials for the manufacture of special cements I have shown that a few straight lines in the cement four-matter parallelogram could replace mathematical calculations, taking hours as had been admitted by well known cement experts. For the design of concrete mixes, especially under the forementioned conditions this method would give not only the percentages of all components required for the fresh concrete but at the same time also some important properties for the various percentages, giving hints as to how the designing has to be continued. Like a war map it would show all the points concerned whether they proved to be right or wrong and it might be a great help to clear some of the still open problems.

As to the "Function of Entrained Air in Portland Cement" I appreciate very much the contributions by H. L. Kennedy and I would like to make a few more comments:

1. Though "the enhanced durability of a concrete is attributable to the entrained air rather than to the agent" I am of the opinion that still very much depends also on the chemical composition of the agent with its special effect chemically and physically on water, cement, aggregates and on any other admixture added to the same concrete to improve its qualities in a higher degree than can be done with an air-entraining agent "only" or to compensate for any deficiencies due to the use of the latter.*

2. In my previous discussion of Mr. Kennedy's paper (in the ACI JOURNAL *Supplement* Nov. 1943) I remarked to 1 (a) that "agents for air entraining only are not expected to improve the consistency of cement paste even from the theoretical point of view". The reason is that portland cement powder is known to be hydrophobic—its grains more or less opposed to being wetted and mixed with water. Any additional air which is entrained to a neat cement paste by means of an air entraining agent is therefore expected to increase the hydrophobia of the cement grains and thus to decrease the consistency, workability, and quality (strength, etc.) of the cement paste, unless some other additional admixture is used which makes the surface of the cement grains hydrophilic, contributing to readily mixing with water. To a certain degree the same is true with rich mixes of concrete or mortar which often need more water than without admixtures when an air entrainment agent "only" is used which has no special chemical effect on the surface of the cement grains.

3. In my forementioned discussion I remarked to 1 (b) that I, too, as a consultant with a London firm had carried out tests on mixtures of standard sand and water but that my mixtures contained a much lower percentage of water than indicated in Mr. Kennedy's paper "thus more nearly corresponding to the water content usually wanted for the fine sand in concrete". While he showed the "effect of air entrainment on flowability of sand water mixtures which contained 25 grams of standard sand and 12 c.c. of water "i.e. 48 per cent of the weight of sand I had carried out my tests with 100 grams of standard sand and 10 c.c. of water, i.e. only 10 per cent of the weight of sand

*On this special effect depends not only the more or less high percentage of entrained air but also the size, shape and distribution of air voids both in the freshly made and in the hardened concrete. In my discussion in the ACI JOURNAL, June 1943 I pointed out that the latter have a great influence on the amount and the speed of water absorption etc. and are thus much more decisive regarding the durability of concrete than small differences in the percentage of air voids. This problem has been investigated very thoroughly in reference to the durability of natural stones and some methods of testing, especially the so-called "Water Saturation—Coefficient", are valid also for concrete and other artificial stones. It is not just a question of simply adding an agent and entraining so many per cents of air, but of when and how it is advisable to do so, and with which kind of agent we shall get the best results, whether it is to be added alone or together with other admixtures as mentioned before.

instead of 48 per cent. Mixed with various suitable air-entraining agents my harsh sand water mixtures became very soft, nearly fluid and looked and behaved nearly like a real mortar containing cement. I got the same results when I replaced the 100 grams of standard sand by sand up to $\frac{3}{16}$ in. as used for concrete. I was glad to learn that since Mr. Kennedy made similar experiments and that he added also the coarse aggregate, so that the mixtures looked and behaved like concrete instead of like mortar only. Although the coarse aggregate is not essential for investigations regarding the function of entrained air, these investigations are of great importance since they led to the warning that "unwarranted reduction in cement content may inadvertently result to the detriment of the finished concrete".

4. The investigation regarding the relation between the sizes of the sand grains and the percentage of entrained air is of great interest, especially the statement that the sand grains under size 100 were not able to entrain air. I was always opposed to any considerable amount of such fine sand in concrete since it increases considerably the water-cement ratio with all the consequent disadvantages. If this fine sand under size 100 could actually be replaced by entrained air acting as "a ring of ball-bearing—like air bubbles" it would mean a real progress. I have been investigating this question for some time and I shall continue to do so from various angles. Though I agree that air-entraining agents and entrained air have the major effect on the sand I am of the opinion that it is a combined action on water, cement, aggregates and other admixtures the details of which have still to be investigated further.

Without doubt the leading manufacturers of admixtures to cement, mortar and concrete are most competent to solve these problems, and I feel sure that in the near future their achievements in the interest of the building industry will be highly appreciated even by those who have still been reluctant to do so.

A part of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE Vol. 40

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Freezing and Thawing Tests of Concrete Made With Different Aggregates*

By STANTON WALKER†
Member American Concrete Institute

SYNOPSIS

Summarizes information on freezing and thawing tests of concrete made with different coarse aggregates and describes a "durability factor" which may be calculated as a function of the cycles of freezing and thawing and their effect on the modulus of elasticity of the concrete as measured dynamically.

It is trite to say that soundness is a most important characteristic of concrete aggregates. It is none-the-less true, even though we don't know how to measure that characteristic with assurance.

Because of the importance of that problem, the National Sand and Gravel Association Research Foundation at the University of Maryland has devoted a major portion of its attention during the past three years, to freezing and thawing tests of concrete made with different aggregates—both fine and coarse.

In general, our tests in comparisons of aggregates are made with concrete of about 3- to 4-in. slump containing 5.5 sacks of cement per cubic yd. Coarse aggregate is graded from No. 4 to 1 in. and incorporated in the concrete in a stream-wet or vacuum-saturated condition. Specimens are beams 3 by 3½ by 14 in. (earlier work) or 3 by 4 by 16 in. (later work). The beams are cured in the moist room for 28 days, then in water at room temperature for 28 days and, finally, in water at 40 F. for 7 hours, before freezing and thawing is started. The freezing and thawing cycle is 17 hours in air at 0 F. and 7 hours in water at 40 F.—these temperatures being controlled within about ± 2 F.

*Presented March 2, 1944, at Open Session of Committee 115, Research, at 40th Annual ACI Convention Chicago.

†Director of Engineering, National Sand and Gravel Association, Washington, D. C.

The effect of freezing and thawing is measured by the modulus of elasticity of the specimen measured dynamically. The test is continued until the modulus of elasticity is reduced about 50 per cent, when strength in flexure is determined. Frequently, but not always, standard-cured specimens are available for comparative strength tests. Thus far about 70 coarse aggregates have been investigated—more than a year's work for an ice box with a capacity of about 50 beams of the dimensions used. Other freezing and thawing investigations also have been made, involving a number of variables including moisture condition of concrete, curing conditions, etc.

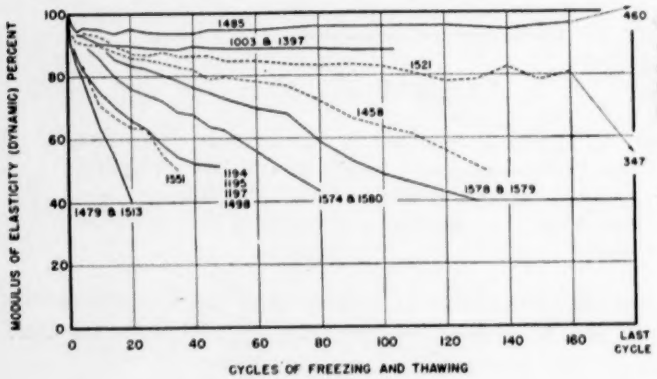


Fig. 1 — Freezing and thawing tests of concrete made with typical coarse aggregates

Fig. 1 shows results of 16 gravels selected as being representative of the range in results which have been found. Limitations of time do not permit of a description of each of them, but one somewhat disturbing fact can be stated which applies to all of them; they are from established sources, most of them have been used in important structures over a period of years, and most of them are considered to have acceptable service records.

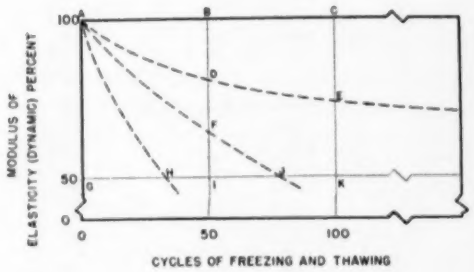
Perhaps the significant fact revealed by these data is that the exposure is too severe—that we have "hit them with too heavy a hammer." The condition of the aggregate when incorporated in the concrete and the curing condition of the concrete were such as to make the specimens about as vulnerable as they could be made to disruption by freezing. On the other hand, a clear separation in the resistance of these concretes is revealed which might not be so apparent under less severe treatment.

In studying a number of variables it would be convenient to be able to indicate resistance to freezing and thawing by a single number. The percentage loss in E at a stated number of cycles has been suggested, but if a number of cycles large enough to be significant is chosen much concrete may have completely failed at a fewer number and the opportunity for a quantitative measure is lost. The number of cycles at which a

stated loss is suffered has been suggested but, frequently, it becomes evident that the concrete will not be deteriorated significantly by any reasonable number of cycles (consider, for example, lot 1485 on Fig. 1 which was still good at 460 cycles) and, again there is no quantitative measure.

We are now studying the significance of a "Durability Factor" which is a function of the area under the curve resulting from plotting modulus of elasticity, expressed as a per cent of the value at 0 cycles, in relation to the number of cycles. For convenience of calculation use is made of the percentage of E at 0 and each succeeding 5 cycles up to the arbitrarily chosen end-point.

Fig. 2—Method of calculating durability factors



CURVE	DURABILITY FACTORS	
	AT 50	AT 100
ADE	$\frac{ADIG}{ABIG}$	$\frac{AEKG}{ACKG}$
AFJ	$\frac{AFIG}{ABIG}$	$\frac{AJG}{ACKG}$
AH	$\frac{AHG}{ABIG}$	$\frac{AHG}{ACKG}$

Fig. 2 illustrates the method of calculating the factor and reveals something of its significance. The durability factor is the area under the curve, above the 50 per cent E line and to the left of the "end-point" cycle, expressed as a percentage of the total area bounded by the zero cycle line, the "end-point" cycle line and the 50 and 100 per cent E lines —in other words, the area under a "curve" showing no effect from the freezing and thawing.

A formula for the durability factors shown in Fig. 1 may be written in general form as follows:

$$F = \frac{10}{n}(\Sigma P - \frac{P_n}{2} - 10n - 50)$$

Where,

F = Durability factor, the area under the curve to the left of the nth cycle and above the 50 per cent dynamic E line, expressed as a percentage

of the total area to the left of the nth cycle and above the 50 per cent dynamic E line.

n = any selected number of cycles of freezing and thawing divisible by 5.

P = percentages of dynamic E at 0 cycles and at each 5th cycle up to and including the nth cycle.

The Durability Factors for the aggregates shown in Figure 1, calculated in this fashion, are shown in Table 1.

Table 1. Durability Factors of Concrete Shown in Fig. 1

Lot No.	Durability Factor At 50 Cycles	At 100 Cycles
1485	89	90
1397	82	79
1003	79	78
1521	79	73
1458	72	59
1579	67	47
1578	65	44
1574	52	28
1580	51	28
1194	39	20
1195	29	14
1498	28	14
1551	26	13
1197	19	10
1479	14	7
1513	14	7

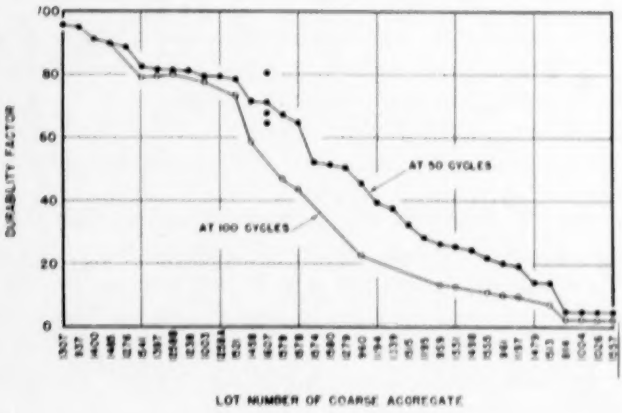


Fig. 3—Durability factor for different coarse aggregates

Fig. 3 summarizes the Durability Factors for 36 samples of coarse aggregate, all from established sources. To furnish some idea of the nature of the materials involved, the aggregates with a Durability Factor "at 50 cycles" of about 90 or better include a "Rocky Mountain" gravel, Long Island quartz gravel, an upper Ohio River gravel and some high quality crushed limestone. The several materials around a Durability Factor of about 80 include glacial gravels from Minnesota and New

England, river gravels from Pennsylvania and a quartz gravel. Potomac River gravel is shown at about 70. Several glacial gravels from the middle west with excellent service records fall between 50 and 70. Other glacial gravels from the middle west, containing various amounts of white porous chert, fall between 25 and 50. One of the materials at about 20 is a crushed limestone. Lot 1513 with a Durability Factor of about 15 is a glacial gravel containing various impurities and is said to, based on a survey of concrete in use up to 10 years, have an acceptable service record in a middle western environment.

These data represent only a portion of that which we have accumulated on the resistance to freezing and thawing of concrete made with different aggregates—both fine and coarse—and tested under various conditions. While it is apparent that a great deal more work is required on the part of a large number of research organizations before a quantitative measure can be found, it is believed that the evidence now before us indicates considerable promise for freezing and thawing tests of concrete as a measure of aggregate durability.

Discussion of this symposium should be submitted in triplicate to the ACI Secretary before September 1, 1944, for publication in the JOURNAL Supplement concluding Proceedings V. 40.

of the total area to the left of the nth cycle and above the 50 per cent dynamic E line.

n = any selected number of cycles of freezing and thawing divisible by 5.

P = percentages of dynamic E at 0 cycles and at each 5th cycle up to and including the nth cycle.

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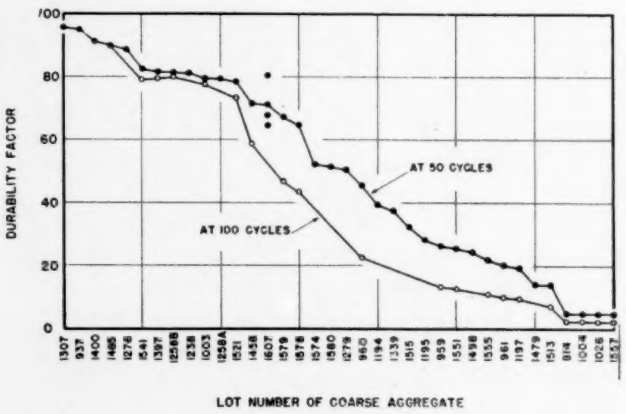
1498	28	14
1551	26	13
1197	19	10
1479	14	7
1513	14	7



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7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN (Supplement) November 1944

Discussion of a paper by Stanton Walker:

Freezing and Thawing Tests of Concrete Made With Different Aggregates*

Discussion by CHARLES E. WUERPEL and AUTHOR

By CHARLES E. WUERPEL†

The idea of indicating, by a single number, the resistance of test specimens of concrete to freezing and thawing is intriguing and is consistent with the prevailing practice of expressing other properties of concrete by single numbers derived from arbitrary tests. In the manner in which they are determined, such properties as compressive and flexural strength, modulus of elasticity, and consistency (slump) are, after all, little more than "single numbers" as far as they are related to the properties of the mass of which the test specimens are considered to be true representations.

An objection to the "durability factor" suggested by Mr. Walker is that the "area beneath the curve and above the 50-per-cent-relative-modulus ordinate" is a generalization—an infinite number of curves could subtend equal areas. The curves A and B in Fig. A represent notably different histories of decrement in dynamic E of two sets of specimens, however, the Walker "durability factors" for the two curves are approximately 66 in both cases.

It may be that the "area under the curve" is adequate for a durability index. It does, in a rough way, take into account the over-all history of the specimen during the test insofar as the dynamic E is capable of expressing this history. However, the following question raises itself: Is the *rate* at which deterioration occurs to a given time-period most important or is the *degree* to which disintegration has occurred at the given time-period most important? Or, in other words, can the condition of the specimens represented by curves A and B in Fig. A be considered equal at the 200 cycle time-period or is specimen A superior to

*ACI JOURNAL, June 1944; *Proceedings* V. 40, p. 573.
†Engineer-in-Charge, Central Concrete Laboratory, War Department, Mount Vernon, N. Y.

specimen B even though evidence of deterioration was noted dynamically at any earlier age than in specimen B?

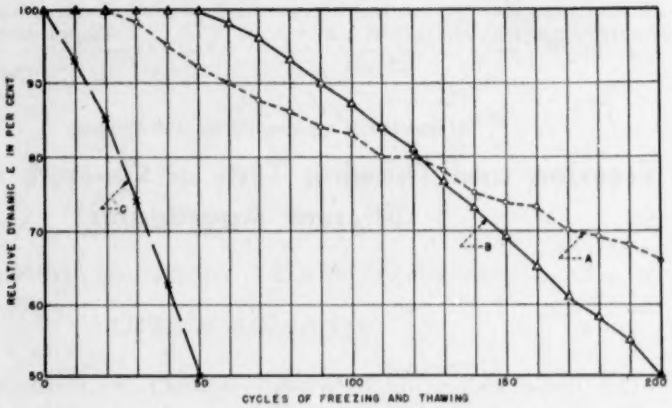

Fig. A—Change in relative dynamic E with freezing and thawing

If it could be assumed that the degree of deterioration at the given end-point of time or cycles was the most important factor, the rather lengthy summation in Mr. Walker's formula could be obviated by the much simpler formula:

$$D.F. = \frac{PN}{M}$$

where: $D.F.$ = Durability factor in per cent of dynamic modulus at zero cycles.

P = Relative dynamic E of 50 per cent or greater

N = Number of cycles at which P reaches 50 per cent or the ultimate number of cycles of the test if P does not reach 50 per cent prior to the ultimate cycle.

M = Ultimate number of cycles of the test.

In all cases where the decrement in dynamic E is less than 50 per cent at the ultimate cycle, the durability factor would be simply P—the relative dynamic E in per cent.

By this method, the curves in Fig. A would be represented by the following durability factors at 50 and 200 cycles:

Curve	*D. F.*	
	50 cycles	*200 cycles*
A	91	67
B	100	50
C	50	12.5

To this writer, these values appear to represent the comparative conditions of the specimens at the two end points better than do the values obtained by Walker's method and the arithmetic is simpler.

However, in either case, the degree to which arbitrary assumptions are made is great.

Before either method, or any variation of the two could be made acceptable for general use, the following would have to be generally accepted:

(a) That the decrement in the dynamic modulus of elasticity presents a true picture of progressive deterioration in concrete.

(b) That 50 per cent relative dynamic E is an adequate "end point" for a freezing and thawing test.

(c) That a particular exactly-standardized procedure for freezing and thawing of specimens of a standard size prepared under standard conditions was adequate as a reference test.

This discussion is not presented as a pessimistic destructive criticism of Mr. Walker's paper or of the idea of a durability factor. The need is very great for a proper and adequate accelerated procedure for testing the durability of concrete and for a mode of expressing in simple terms the results of such tests. It is hoped that the original paper and this discussion will serve to whet the interest in this subject and accelerate progress toward attainment of the necessary goal.

It is hoped that Mr. Walker will present the more general formula, for any desired interval, for calculating his durability factor in his closure to the discussion. The formula given in his paper is restricted to intervals of 5 cycles and such small intervals are unnecessary and excessively laborious in cases where the end point may be at 200, 500 or 1000 cycles rather than the 50 and 100 cycles indicated in his Table 1.

AUTHOR'S CLOSURE

Mr. Wuerpel raises some extremely pertinent questions as to the adequacy of the "durability factor" proposed by me *for consideration* as a measure of the resistance of concrete to freezing and thawing. It may be worth while to remind the reader that the factor was not represented as an adequate, quantitative measure. It was said only that "it would be convenient to be able to indicate resistance to freezing and thawing by a single number" and that "we are now studying the significance of a 'durability factor.' "

Mr. Wuerpel suggests another factor simpler of calculation which he infers may be as significant as that proposed in the original paper. I am not disposed to object to that point of view. It *is* simpler of calculation and, while it depends on only one point on the curve, the order of magnitude of the values is not greatly different from those given by the "rather lengthy summation" which gives weight to the *path* of the

curve. In fact, the two factors are identical when the curve is a straight line.

It might be argued that the original factor, which takes into account the *rate* and *degree* of deterioration, is more significant than one which takes account only *degree;* but in the present state of the art it is probable that the accuracy of measurement of deterioration is low enough to make any such argument little more than a quibble. Table A repeats the durability factors shown in Table 1 of the original paper and compares them with Mr. Wuerpel's modified factor. Table B repeats the factors tabulated in Mr. Wuerpel's discussion and compares them with factors calculated by the formula in the original paper.

TABLE A—DURABILITY FACTORS OF CONCRETE MADE WITH DIFFERENT COARSE AGGREGATES

Concrete contained approximately 5¾ bags of cement per cu. yd.; slump 3 to 4 in.; coarse aggregate vacuum saturated and graded No. 4 to 1 in.; same cement and sand used in all tests. Concrete specimens 3x3½x14 in.; cured 28 days in moist room and 28 days in water before freezing in air at 0 F. for 17 hours and thawing in water at 40 F. for 7 hours.

	Durability Factors at			
	50 cycles according to		100 cycles according to	
Lot No.	Walker	Wuerpel	Walker	Wuerpel
1485	89	94	90	96
1397	82	90	79	85
1003	79	88	78	88
1521	79	85	73	83
1458	72	79	59	64
1579	67	73	47	50
1578	65	72	44	50
1574	52	62	28	32
1580	51	63	28	35
1194	39	50	20	25
1195	29	50	14	25
1498	35	53	18	30
1551	26	32	13	16
1197	19	28	10	14
1479	14	17	7	8
1513	14	16	7	8

TABLE B—COMPARISONS OF DURABILITY FACTORS

	Durability Factors at			
	50 cycles according to		200 cycles according to	
Curve	Walker	Wuerpel	Walker	Wuerpel
A	96	91	67	67
B	100	100	66	50
C	56	50	14	12.5

Mr. Wuerpel lists three points which must be accepted "before either method, or any variation of the two, could be made acceptable for general use". The first, "that the decrement in the dynamic modulus of elasticity presents a true picture of progressive deterioration in concrete" goes far beyond the question of the adequacy of any "durability factor" designed to represent a picture of the "decrement curve" by a single number. It has to do with the significance of the application of sonic methods—a question to which further attention is given later in this discussion. The second question, if 50 per cent is an adequate end-point, does not affect the basic idea; any other end point can be applied just as readily. That, and the desirability of choosing some end-point short of complete disintegration will be discussed later. His last point, that of an "exactly-standardized procedure", goes to the broad question of the significance of freezing and thawing *per se* as a measure of durability of concrete.

Comparisons of decreases in modulus of elasticity with decreases in flexural strength lend strong support to the belief that the "decrement in the modulus of elasticity" is significant. F. V. Reagel of the Missouri Highway Department made a comprehensive study of the relationships involved. His data are summarized in Fig. 4 of a paper entitled "Freezing and Thawing Tests of Concrete." * A reasonably good relationship

Proceedings, Highway Research Board, V. 20, p. 587 (1940).

TABLE C—COMPARISONS OF MODULUS OF ELASTICITY AND FLEXURAL STRENGTH OF CONCRETE SUBJECTED TO FREEZING AND THAWING

Series No.	Concrete or Mortar	Principal Variable	Ave. Last Cycle	Percent of Value at Start of Freezing and Thawing	
				Sonic Modulus	Flex. Strength
39	Concrete	Source of Sand	150	66	64
			150	77	76
			48	48	37
			38	50	34
			56	49	35
			125	46	48
			39	43	28
			150	94	90
39A	Mortar	Source of Sand	220	94	101
			220	95	103
			220	97	113
			220	93	92
			220	93	96
34CA	Concrete	Degree of Saturation of coarse aggregate	26	40	33
			39	43	37
			54	40	33
			77	43	32
			144	42	32

is shown which he expresses as $R = 6E^{0.6}$, where R is per cent reduction in flexural strength and E is per cent reduction in modulus of elasticity.

In our own work, in general, strengths have been determined for the frozen and thawed specimen in comparison with a companion specimen cured under standard conditions. The data add strong support to the belief that reductions in modulus of elasticity are of *approximately the same order of magnitude* as reductions in flexural strength. For purposes of illustrations only, Table C summarizes representative data from three different series of tests conducted by the National Sand and Gravel Association Research Foundation at the University of Maryland.

The desirability of establishing an end-point significantly short of complete disintegration may be supported by a number of reasons among which the following stand out:

(1) Measurements of fundamental frequency, from which the modulus of elasticity is calculated, become extremely erratic after the modulus of elasticity has been significantly reduced. In our case a 50 per cent end-point was selected as being about the lowest value for which even an approximately satisfactory degree of uniformity could be maintained for companion specimens. After a loss in modulus of elasticity of about 50 per cent is suffered, companion specimens begin to behave so erratically that no average of results can be calculated with confidence.

(2) The discontinuation of freezing and thawing at a point when significant strength determinations can still be made has seemed necessary in any consideration of the significance of dynamic E tests.

(3) Concrete subjected to any sort of stress—highway slabs, for example—would appear to have had their value substantially destroyed when their ability to sustain stress has been reduced in the neighborhood of 50 per cent.

However, as pointed out earlier, the calculation of a "durability-factor" is not tied to the selection of any one end-point, nor, as Mr. Wuerpel has pointed out, to determinations of E at each 5 cycles. It should be kept in mind that the formula in the original paper is only an *arithmetic* device for determining the area under some selected portion of the "modulus-decrement curve" expressed as a percentage of the area of a selected rectangle. Such boundaries as are desired may be established. The formula in the original paper may be written in general terms as follows:

$$F = \frac{100i}{(100-L)n}\left(\Sigma P - \frac{P_n}{2} - \frac{Ln}{i} - 50\right)$$

Where,

F = Durability factor, the area under the curve to the left of the nth cycle and above a *selected* percentage (L) of dynamic E line, expressed

as a percentage of the total area to the left of the nth cycle and above the *selected* percentage (L) of dynamic E line.

L = selected end-point in modulus of elasticity.

i = number of cycles between successive values of dynamic E used in the calculation.

n = any number of cycles of freezing and thawing divisible by i.

P = percentages of dynamic E at O cycles and at each *ith* cycle up to and including the *nth* cycle, but with all values lower than L considered to equal L.

It should be realized that the accuracy with which F represents an irregular curve decreases as the interval i is made larger.

No further comments on Mr. Wuerpel's third point suggest themselves except to express complete agreement with the thought that an "exactly-standardized procedure" correlated with field performance is essential to the use of freezing and thawing tests as a quantitative basis for acceptance. However, to repeat the last sentence of the original paper, "while it is apparent that a great deal more work is required on the part of a large number of research organizations before a quantitative measure can be found, it is believed that the evidence now before us indicates considerable promise for freezing and thawing tests of concrete as a measure of aggregate durability."

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Current Reviews

of Significant Contributions in Foreign and Domestic Publications, prepared by the Institute's Reviewers

A small reinforced concrete dam

G. HOWARD HUMPHREYS, *Concrete and Constructional Engineering*, V. xxxviii, No. 12, Dec. 1943, pp. 367-77.
Reviewed by GLENN MURPHY

Design features of a buttress type reinforced concrete dam 403 ft. long. The buttresses are spaced 12 ft. o.c., and the facing slab is 12 in. thick, inclined at 45 degrees. The flood level, controlled by a 14-ft. spillway, is 26.5 ft. above the base of the dam. The foundation slab, with a 12 ft. cut-off wall, rests on a clay subsoil.

New method to determine moisture content in sand

C. R. WATERS, *Engineering News-Record*, V. 132, No. 10 (Mar. 9, 1944), p. 115.
Reviewed by S. J. CHAMBERLIN

The method is not new, being merely an adaptation of the displacement method. A metal container holding 2 kg. of water is partially filled and the moist sand of a weight in kilograms equal to its specific gravity is added. The container is filled to overflowing with water, struck off with a metal straight-edge and weighed. Knowing the specific gravity and the combined weight, the percentage of moisture is obtained from a table.

New system of climbing shuttering

Concrete and Constructional Engineering, V. xxxviii No. 12, Dec. 1943, pp. 389-90.
Reviewed by GLENN MURPHY

Application has been made for a patent on a system of sliding forms for concrete walls. Guide channels are erected vertically about 4 ft. apart. Plates of the desired height are inserted in the groove of the channels producing the forms for the walls. The plates can be slid up the channels as the work progresses. Methods of holding the channels in position and taking up the play between the plates and the channels are described.

Concrete arch quantities by graphics

T. W. OLIVER, *Engineering News-Record*, V. 132, No. 10 (Mar. 9, 1944), pp. 116-117.
Reviewed by S. J. CHAMBERLIN

The shape of the sloping wings and wing-parapets of the arch culverts are such as to make strict mathematical calculation of their volumes impractical. Large scale drawings, usually ½-in. to the foot, of the side elevation and plan of the sloping wings are prepared. Vertical sections are cut through at frequent intervals and projected onto an end elevation. These projected areas are "planimetered" and the volume computed by the average-end-area method.

Reinforced concrete sluice gates

Concrete and Constructional Engineering, V. xxxix, No. 1, Jan. 1944, p. 20.

Reviewed by GLENN MURPHY

Reinforced concrete sluice gates 4 ft. 7½ in. high, 2 ft. 11¼ in. wide, and 2¼ in. thick were used in the reconstruction of an old weir at Aston Cantlow by the Warwickshire County Council. No. 5 gauge twisted rods were used for reinforcement, while 2-in. by 2-in. by ¼-in. steel angles were used as facing for the sides and bottom of the gates. The piers, guide piles, foot bridge, and other appurtenances were also of reinforced concrete. The concrete mixture contained 120 lb. of cement to 4 cu. ft. of ½ in. max. aggregates.

Concrete bridge girders reinforced with old steel

N. C. RAAB, *Engineering News-Record*, V. 132, No. 6 (Feb. 10, 1944), p. 81.

Reviewed by S. J. CHAMBERLIN

A pair of steel girders 110 ft. long and orginally 9 ft. 3 in. deep were cut in two longitudinally and used as reinforcing for the concrete beams of a highway bridge having a central span of 80 ft. and two cantilever arm approaches of 15 ft. each. Width of the concrete girders varied, in accordance with shear requirements, from 1½ to 2½ ft. This was easily done because the greater width could be provided in forms that were suspended from the steel girders. Horizontal shear was cared for conveniently by the stiffners, and lugs were welded to the stiffners and upper faces of the flanges for bond. The flanges of the steel girders were left exposed on the under side of the beams.

Air-entraining cement concrete proves scale resistant (a correction)

E. F. YOUNG, *Engineering News-Record*, V. 131, No. 27 (Dec. 30, 1943), pp. 54-57.

Reviewed by S. J. CHAMBERLIN

A review p. 331, ACI JOURNAL, Feb. 1944, was in error. The sentence "After 4 years of service, sections made with the air-entraining cement are sound and free from scale except for one gutter section where there is some scaling, whereas heavy salt solution is carried from a street-car switch,", should have been merely "After 4 years of service, sections made with the air-entraining cement are sound and free from scale."

The error arose in a too hasty combination of the corrected sentence above with a sentence of the original paper as follows: "Where the entire street *with the exception of 18 and 30 in. gutter placed in 1937*, was paved with air-entraining portland cement, there is no indication of scaling *except on the gutter section*."

Pre-stressed reinforced concrete

K. HAJNAL-KONYI: *Archt. J.*, 1943, 97 (2519), 300-2. Building Science Abstracts, V. XVI, (New Series) No. 10, Oct. 1943. HIGHWAY RESEARCH ABSTRACTS

The principles and advantages of pre-stressing reinforced concrete are described; the steel economy factor is emphasized as well as the possibility of eliminating all tensile stresses in concrete members up to a maximum calculated load. Various methods of applying the stretching force are discussed: (a) by "post-stressing" after most of the concrete shrinkage has occurred; post-stressed ties in bowstring bridges and lattice girders, as well as reinforced concrete girders up to 260 ft. span, have been provided by this means, particularly in Germany, (b) by pre-stressing with high tensile steel wire, 0.04 to 0.2 in. diameter, up to 200,000 psi according to the processes of Freyssinet and Hoyer. Hoyer, in Germany, has developed the mass production of pre-stressed beams for housing purposes, the concrete having a compressive strength of 10,000 psi, with an admitted "working stress" of 3000 psi. These stresses provide a safety factor of 1.5 against cracking and 3 against failure.

A brief history of lime, cement, concrete and reinforced concrete

J. O. Draffin, *Journal, Western Soc. Eng.*, V. 48, No. 1 (Mar. 1943) pp. 14-47. Reviewed by F. E. Richart

The author has used great care and discrimination in preparing this brief but accurate history of the development of lime, cement and concrete. An interesting account is given of the development and use of lime mortar, hydraulic lime, natural cement and portland cement, with an appraisal of the contributions of various discoverers and users in Europe and the U. S. Emphasis is placed on the physical and chemical properties of modern portland cements. Attention is given to the development of methods of proportioning of concrete, with mention of the contributions by Feret, Fuller and Thompson, Edwards, Abrams, Talbot and others. The remainder of the paper is devoted to the development and special uses of reinforced concrete, with especial attention to patented "systems" and monolithic members and structures, such as buildings, bridges, roads, etc., to which its adaptability makes it especially useful. The paper is well documented, instructive and interesting.

Old concrete highway pavements salvaged

Rex M. Whitton and J. D. Chadwick, *Engineering News-Record*, V. 132, No. 12 (Mar. 23, 1944), pp. 94-97. Reviewed by S. J. Chamberlin

With the belief that the most critical failure of concrete pavements is caused by "slab pumping" the Missouri State Highway Department is salvaging old pavement by a combination of mudjacking and "decking." A slurry mixture of 4 bags of cement per cu. yd. of sandy loam topsoil with 50 to 55 per cent of water added in the pug mill is mudjacked into holes cut into the pavement adjacent to transverse joints and cracks. The wet mixture is used to give a large spread under the pavement and to fill small voids and channels. The slurry leaked through to the top of pavement at cracks 20 and 25 ft. from the point of injection. A bituminous deck is added to aid in water-proofing the surface of the concrete that has numerous transverse cracks and to restore the riding surface and thereby reduce impact.

Reinforced concrete poles for power lines

V. Subramaniam, *Indian Concrete Journal*, V. 17, No. 7, July 1943, page 203. Reviewed by J. C. Pearson

The author, a structural engineer for a well known concrete products firm in South India, tells in this 4000-word article a very complete story of concrete poles for power lines. The introduction refers briefly to the early use of such poles in America and Europe, discusses their advantages in comparison with wood and steel poles, and describes the several types which may be successfully manufactured. About one-half the text gives a simple outline of design requirements and how they should be met, a brief reference to pole fixtures, and a short mathematical discussion of foundation design. The last section of the paper is devoted to manufacture under the headings: Concrete, steel, molds, finish, costs, and methods of testing poles. The author concludes that the success which had been attained in the installation of several hundreds of reinforced concrete transmission poles built by his firm indicates that this type should find wide use in India, especially in locations where wood or steel poles would be of doubtful economy or service.

Gravel and stone in comparable mixes

W. S. Elliot, *Engineering News-Record*, V. 132, No. 6 (Feb. 10, 1944), pp. 93-95. Reviewed by S. J. Chamberlin

Test specimens were made from dolomitic limestone and quartz gravel from the New York area using 4, 5, 6 and 7 bags of cement per cu. yd. The aim was to maintain the consistency of the concrete to that represented by a standard slump of 4 to 5 in. A Type II cement with finely graded sand was used for Series I, and a Type I cement and a

coarser sand was used for Series II. Except for the 7-day tests of Series I, the water-ratio strength curves for the crushed stone concrete are somewhat higher than for the gravel concrete. When the strength is plotted against the cement factor, the gravel concrete curves for Series I are generally higher, the differences being most evident in the leaner mixes and practically disappearing in the 7-sack mixtures. In Series II, the gravel concrete strengths are somewhat higher, for a given cement content, than the stone concrete strengths for the 7-day tests and for the 4 and 5-bag mixtures of the 28-day tests. The 6 and 7-bag concrete, in the 28-day tests, showed somewhat higher strengths for the stone than for the gravel. These results are based on a limited number of tests with two types of locally available aggregate and certain conditions of test. The author emphasizes that they are not necessarily indicative of results to be obtained with all gravels and all crushed stones or with different combinations of these materials.

Rapid and simple concrete proportioning

L. D. Long, *Engineering News-Record*, V. 132, No. 12 (March 23, 1944), pp. 104-107
Reviewed by S. J. Chamberlin

Four empirical charts enable the inspector or engineer not familiar with concrete technology to take unknown aggregates and design successful mixtures. Specific gravities, fineness moduli and weights per cu. ft. of the fine and of the coarse aggregate must be determined. The percentage of voids and consequent percentage of solids in the aggregates may be determined from the first chart. The second chart provides a means for determining one of four factors when the other three are known: (1) added parts of fine and coarse aggregate per bag of cement; (2) slump; (3) water-cement ratio or strength; and (4) fineness modulus of coarse aggregate. The sand is assumed to be 35 per cent of the total aggregate when gravel is used (40 per cent for stone) and the total solids of aggregate per bag of cement is the sum of the products of the density and mixture parts for the fine and coarse aggregate. The third chart represents solid values of the ingredients in a concrete mixture and is used in the determination of bags of cement, total aggregate solids and water per cu. yd. of concrete. The fourth chart is for the determination of the cu. ft. of coarse aggregate per cu. yd. with varying fineness moduli of both fine and coarse material. The difference between the total aggregate and the coarse aggregate gives the amount of fine aggregate per cu. yd. Two examples are worked out, one where the strength or water-cement ratio is specified and another where the cement content is specified.

Norfolk Dam construction expedited to provide power

Engineering News-Record, V. 132, No. 6 (Feb. 10, 1944), pp. 75-80. Reviewed by S. J. Chamberlin

The Norfolk Dam is a plain gravity type structure with a 2,624-ft. crest length, a maximum height of 233 ft. and a concrete volume of 1,500,000 cu. yd. The aggregate plant of 500-ton hourly capacity produces fine aggregate, limestone dust, sand and four sizes of coarse aggregate. Two correlated processing systems are used, one producing 3- to 6-in. aggregate and rock dust and the other sizes of coarse aggregate and sand from limestone which is trucked directly to the primary crusher. The other system processes river sand and gravel, the material being transported from the railroad siding by a seven-flight, 42-in. belt conveyor to the raw storage pile. Flexibility of the plant permits either or both the chert pea gravel and the 1½- to ¾-in. aggregate to be put through the rollers for making sand. The addition of crushed stone is permitted only if the resulting product has a fineness modulus of 3.0 or less. Delivery of materials to a 42-in. belt conveyor in a 9-ft. batching tunnel below the aggregate and sand storage is controlled by automatic weighing batchers.

Mass concrete is of two types, a 3-bag mixture with limestone dust added is used for the interior and a 4-bag mixture for a 5-ft. thick layer at both faces. Low-heat cement

is used in the summer and moderate-heat cement during the winter. During the summer crushed ice of ½-in. maximum size is added, lowering the placing temperature 3 F per 100 lb. of ice to a 4-cu. yd. batch. To speed placing operations, especially equipped trucks pick up and deliver 4-yd. buckets, without the aid of other equipment, to the midpoint of the dam, from there it is transported the remaining distance by 2,846-ft. cableways. The dam is being constructed in monoliths of about 48 ft. average width with a maximum of 5-ft. placements permitted. The forms consist of 1 x 6-in. sheathing covered by plywood and absorbent paper. The panels for the outer faces are 48 ft. long and those for the vertical faces 20 ft. All concrete is vibrated. Curing is by a water spray.

Gain in strength of pavement concrete with age

From 25th Annual Report, Illinois Division of Highways, Materials and Tests Division, p. 132.
HIGHWAY RESEARCH ABSTRACTS

Testing of cores from the same pavements in the past has seldom shown a significant increase in the strength of the concrete from year to year and has resulted in the general conclusion that concrete approaches closely its ultimate strength at the age of about one year and that further gain in strength is slow and relatively insignificant. Recent tests, however, of cores drilled from pavements, ranging in age from 14 to 17 years, show that there is a slow gain in strength, significant over a long period although not noticeable from year to year.

The cores tested recently were taken from 27 pavement sections and, with others taken previously from the same locations, are represented by the strength record shown in Table 1. It will be seen that the increase in strength over the period following the first year was 50 per cent or more of the strength at the age of one year, although it would be difficult to conclude with any degree of certainty that any significant gain in strength existed between consecutive years, at least up to the fifth or sixth year.

When it is considered that the number of cores tested at each age is fairly large and, if judged by laboratory experience, it would seem that the increase in strength which on the average amounts to about 200 lb. psi per year should have been easily discernible from the data. However, a mathematical comparison between core strength results

TABLE 1—PAVEMENT CORE STRENGTHS FOR AGES UP TO 17 YEARS

Age in Years	½	1	1½	2	2½	3	3½	4	4½
Number of cores tested	28	54	25	46	36	126	51	165	28
Average strength-pounds per square inch	4,500	4,764	4,581	4,793	4,664	5,025	5,560	6,095	5,086

Age in Years	5	6	7	8	14	15	16	17
Number of cores tested	271	199	143	83	47	93	55	115
Average strength-pounds per square inch	5,627	6,279	6,665	6,811	7,962	7,971	7,898	7,372

of tests of 6 in. by 12 in. cylinders in the laboratory, based on the theory of errors, indicates that pavement concrete is subjected to extreme variability in comparison with concrete mixed in the laboratory under controlled conditions. In fact, it may be shown that the average result obtained from a sample of about 18 cores drilled from a pavement would not be expected to indicate the true average strength with any greater accuracy than the result obtained from the test of a single 6 in. by 12 in. cylinder made and tested in the laboratory with all known causes of variability eliminated. This being the case, the core test results presented herein, despite the fairly large number of specimens tested

at each age, would be expected to be of no greater accuracy than that necessary for establishing a trend. It may also be concluded that failure to discover gain in strength from year to year in the past has been due to the fact that the number of cores taken at any one time has been wholly inconsistent with the degree of variability existing in pavement concrete.

Crystals from portland cement hydration

C. M. Slipecevich, L. Gildart and D. L. Katz, University of Michigan. *Industrial and Engineering Chemistry*, V. 35, No. 11, Nov. 1943. Highway Research Abstracts

Summary and Conclusions: (1) Crystals, formed by hydration and hydrolysis of portland cement compounds in water with subsequent evaporation of the water during preparation of the specimen, have been examined with the electron microscope. Approximately a thousand visual observations were used in assembling the data. (2) Gypsum forms monoclinic type crystals in all cases. (3) Although calcium hydroxide gives spheres as its principal product, a fibrous or neddlelike structure is also often observed. (4) Calcium carbonate forms rhombic slabs which adhere to one another as judged by the products of carbonation of calcium hydroxide. (5) Dicalcium silicate initially hydrates to rhombic slabs which adhere to form accordion-shaped aggregates. Later, amorphous spherulites are found. (6) Tricalcium silicate hydrates to form the same products as dicalcium silicate in addition to calcium hydroxide. (7) Tricalcium aluminate, which may contain small amounts of the mono- or dicalcium compound and lime, gives rhombic slabs, thin hexagonal plates which resemble kaolin, and spherulites. In several instances needles and splines have been observed, but sulfate contamination could possibly have accounted for this third type of crystal. (8) Tetra-calcium aluminoferrite decomposes after several hours to form the same products as tricalcium aluminate, plus a background of ferrite and possibly calcium hydroxide. The 3-hour hydration sample gives a unique unstable chain structure not found in any other specimen. (9) Mixtures of gypsum with tricalcium aluminate and with tetra-calcium aluminoferrite produce heavy splines. Some fractures of these splines indicate that they may be hollow with fibrous walls. (10) Both dicalcium silicate and tricalcium aluminate hydrolyze or change after several days of hydration in a relatively large quantity of water to yield spherulites which appear similar to calcium hydroxide. (11) Although calcium carbonate, dicalcium silicate hydrate, and one product of hydration of the tricalcium aluminate all form similar rhombic slabs, the authors believe them to be separate crystals. (12) With the possible exception of gypsum and the thin hexagonal plates formed from the tricalcium aluminate sample, portland cements show all, but no more, crystal forms than those which have been observed from the pure compounds or mixtures. (13) The crystallization taking place in this research may be somewhat different from that when a minimum of water is present and the material is gelatinous. However, when considered on the basis of phase equilibrium, the specimens used here always contained an excess of the original material to keep the solution saturated. Crystallization is likely to come from a saturated solution, and therefore the equilibrium phases should be identical regardless of whether an excess of water is present or whether they are only partially hydrated as a result of the smaller quantity of water used to dissolve the original material. However, the wide dispersion of the samples required in order to observe crystal structure made the dilute dispersion necessary for this study. (14) Under the conditions of these experiments all substances show crystalline or geometric shapes except the deposit of ferrite and the material resembling calcium hydroxide. The amphorous material formed from tricalcium silicate, dicalcium silicate, and tricalcium aluminate, after long periods, resemble calcium hydroxide but could be colloidal forms of the silicate and aluminate. If these spherulites are the final form of dicalcium silicate and tricalcium aluminate, the colloidal theory becomes more plausible. How-

ever, in that case the hydrate of tricalcium aluminate should be written with a variable water content rather than with 6 molecules of water. (15) If these results can be correlated with portland cement reactions occurring in ordinary industrial proportions of water to cement, it may safely be concluded that the strength of the concrete is attributable to an abundance of crystals in the form of splines, needles, and fibers matted together and bonded by the amorphous mass. Further, strength may be imparted by laminations and the strong surface forces of numerous thin platelike crystals.

A review of the evidence concerning expansive reaction between aggregate and cement in concrete

A. R. Alderman, Commonwealth of Australia, Council for Scientific and Industrial Research, Melbourne, 1943, Bulletin No. 161, p. 15. Highway Research Abstracts

Recent work indicates that expansion-causing reaction is likely to take place when certain "dangerous" aggregate components are used with cements rich in potassium or sodium. Precise knowledge of what constitutes an aggregate dangerous in this way is very limited. Stanton's work gives very strong evidence that opal, and rocks containing opaline silica, will cause expansion. Other evidence suggests strongly that ground-mass material—glass or very fine crystals—in certain volcanic rocks may be dangerous. These and some similar items of evidence are new and can be taken as important. Other rocks which have been suggested as reactive, phyllite, chert, rocks containing decomposed felspar, shale, are materials which, owing to their physical or chemical properties, would be regarded as undesirable aggregates quite apart from any possible reactivity with alkali-rich cements. Although observations of actual structures and of laboratory test specimens have shown that the combination of high-alkali cement with dangerous aggregate may cause expansive reaction, the same observations have also shown that similar reaction is most unlikely when such cement is used with aggregates free from the dangerous constituents. Expansion is also unlikely when low-alkali cement is used even with dangerous aggregate. The last statement may need to be qualified, for Hanna (1941) has described an instance where expansive reaction seems to have taken place without any assistance from the alkali components of the cement. The dividing line between high- and low-alkali cements is a controversial point. The division was originally made by the California Division of Highways which modified its specifications for cement to be used in those parts of the State in which the local aggregates are regarded as dangerous. The specifications limited the total alkali-content to 0.50 per cent; the word alkali being used for the sum of Na_2O and K_2O calculated as Na_2O. The figure was later raised to 0.60 and has since been adopted by a number of consumers. Stanton states that the expansion is of such low order as to be negligible when the alkali-content of the cement is less than 0.60 per cent.

The figure by which cements are judged as being low in alkalis has, of course, been fixed merely as a safety measure and is based on a certain amount of statistical evidence.

It is, however, likely to lead to many anomalies. No consideration is given to the possibility that potassium and sodium may have somewhat different effects. In cement clinker there is good evidence to show that potassium is combined in at least two different ways. These potassium-containing compounds probably differ in their readiness to react with aggregate materials. Similar remarks may well apply to sodium, and these points are well supported by the variable water-solubility of the alkali-constituents of cement. It is thus not necessarily true that a cement containing 0.4 per cent total alkali will have less alkali in potentially reactive form than a cement which has a total content of 0.8 per cent. Until more is known about the chemistry of the alkali metals in cement these matters will remain uncertain. It does not appear likely, therefore, that the mere determination of total K_2O and Na_2O will always give a reliable index of the potential reactivity of a cement to be used with trouble-causing aggregate.

In the following list are given types of natural aggregate materials which may enter into expansive reaction in concrete. It will be noted that some materials included here would be regarded as undesirable aggregate components apart from possible reactivity.

(1) *Aggregate materials against which evidence is strong:* (a) Opal and rocks containing opal, e.g., many flints, cherts, and related rocks. In Australia the silicified and partly opalized surface rocks of the arid regions must be regarded with suspicion until they are thoroughly investigated. (b) Volcanic rocks containing much volcanic glass and excessive amounts of very fine particles, e.g., andesite, rhyolite, and felsite. Porous and vesicular rocks will generally be undesirable for this reason as well as on account of their physical properties. (c) Certain shales, phyllites, and schists. Such rocks also possess objectionable physical properties. (d) Selenite (gypsum) and other saline deposits.

(2) *Aggregate materials against which there is some evidence:* (a) Rocks containing olivine and its decomposition products, e.g., serpentine and chlorophaeite. (b) Rocks containing decomposed felspar. This will apply not only to igneous and metamorphic rocks but also to sediments, e.g., felspathic sandstones. (c) Rocks containing microcline-perthite felspar. This is surprising as other felspars appear to be quite safe when fresh. (d) Zeolitic minerals may be undesirable.

It will be seen that definite information on this matter is still limited in extent. Rigorous testing by standard methods such as those recommended by the American Society for Testing Materials would probably exclude many of the materials in the above list. It is obvious, however, that such testing must be supplemented by petrographic examination for possible dangerous constituents. The need for accelerated tests for reactive expansion has been stressed by many writers. At present the most reliable indication seems to be Stanton's test in sealed containers. This, unfortunately, takes some months but should be used until a more rapid method is available.

Some estimate of the chances of failures in concrete due to expansive reaction needs to be made. Before any precautions were taken in this matter the great majority of concrete structures behaved extremely satisfactorily. In the small proportion which have not, the failure can be attributed to a number of causes, such as faults in construction, in the cement, in the physical properties of the aggregates, and in mixing, and to these we may now add cement-aggregate reaction. The relatively small percentage of failures has been mentioned by Blanks (1941) and Tremper (1941). Blanks, in describing the deterioration of concrete at Parker Dam remarks that "this is the only case of comparable disintegration among the fifty-four dams (representing about 30,000,000 cu. yds.) constructed by the Bureau of Reclamation."

For ordinary purposes where well-tried aggregates and cements are to be used together the danger seems to be so small as to be negligible. For large projects where great, masses of concrete are to be used—as, for instance, in large dams—it would appear that in addition to the standard tests, aggregates must be subjected to careful petrographic examination. The aggregate and the cement should also be tested together for expansive reaction—at present by Stanton's method. Should the geographical position of the project dictate that the only aggregate economically possible is one which is likely to react with high-alkali cement, a cement of low alkali-content should be used. The article contains 30 references.

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PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE

VOLUME 40—1944

From JOURNAL OF THE AMERICAN CONCRETE INSTITUTE, Vol. 15, Sept. 1943, to June 1944 and Supplement, November 1944

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Original contributions to the JOURNAL OF THE AMERICAN CONCRETE INSTITUTE—papers, reports, discussions by subject, title and author.

For the convenience of the reader who is referring to JOURNAL issues rather than to Bound Volumes (in which discussion is assembled following the paper discussed) there is a reference to JOURNAL issue in which discussion appeared. This reference to discussion is by supplementary page numbers. If the last page of a paper is 28, the first page of the discussion, published later, is 28 - 1.

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Specific data on Beams are so indexed by reference to ENGINEERING DESIGN or TESTS OF MEMBERS AND COMPLETED STRUCTURES thus avoiding an oversight by the searcher of important allied data.

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